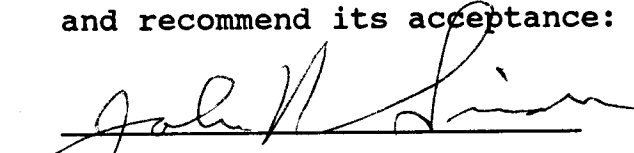
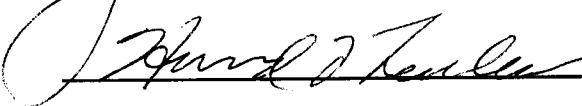


To the Graduate Council:

I am submitting herewith a dissertation written by Denise Ford Jackson entitled "A Methodology for the Quantification of Knowledge Work." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Engineering Science.


Elden L. DePorter, Major Professor

We have read this dissertation
and recommend its acceptance:



John C. Hingerford


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Vice Provost and
Dean of the Graduate School

A METHODOLOGY FOR THE QUANTIFICATION OF KNOWLEDGE WORK

**A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee**

Denise Ford Jackson

August 1989

DEDICATION

This dissertation is dedicated to my family. To my parents who instilled certain characteristics in me that gave me the will to stay the course, I say "Thank You." To my sister, Linda who in her own way offers support, I say "Thank God you're here." To my husband, Andrew, I say "Thanks for the patience and encouragement, along with the love." Mostly, I want to thank God for sending such special people into my life.

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ABSTRACT

This research presents a methodology which permits the quantitative description, analysis, and measurement of knowledge work. The methodology includes a hierarchical structuring of work to identify the level at which the work should be measured and the level at which control should be inacted based on the timeframe in which feedback is provided.

This methodology identifies the appropriate measurement technique based on the characteristics of the work in question. It improves upon the time provided by the measurement to determine a "target" completion time. The procedure for calculating this target time is a function of the amount and type of aggregation required from the measurement level to the control level. Also provided in this methodology are guidelines for selecting parameters which might affect the target time but are often omitted.

The methodology developed in this research provides a structured approach to the problem of measuring knowledge work. Thus, this research is significant in that it presents a framework by which a group traditionally not measured can be measured for the purposes of management and control.

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CHAPTER 1

INTRODUCTION

General Introduction

Declining productivity challenges the economy of the United States today. One reason for this apparent decline is our inability to measure (and thus control) all work performed. Our inability to measure the work performed stems from the rapid increase in "white-collar" (indirect labor categories and service) workers, where we have no satisfactory measurement methodologies; and the corresponding decrease in "blue-collar" (manufacturing and production) workers, where we have good measurement methodologies. The changing nature of all work tasks because of technological advances further complicates any measurement approach. Our inability to measure work becomes especially acute when attempting to measure the productivity of the knowledge worker -- that segment of the white-collar workforce whose jobs entail a significant amount of mental behavior as opposed to skill behavior.

Historically, techniques used for measuring the productivity of blue-collar workers have been inadequate for measuring knowledge workers. The knowledge worker often does not produce a tangible output nor perform

tasks which are patterned or effectively decomposable. Further, literature reveals that tasks performed by knowledge workers have not been fully defined (we are not sure how mental behaviors are executed), and, thus, techniques for measuring their contributions have not been developed. Defining and measuring knowledge worker tasks are imperative if the United States is to reverse its present decline in productivity.

Terminology

The quantification of knowledge work for purposes of productivity measurement is a concept widely discussed in the literature; however, the associated terminology is often used inconsistently by researchers and practitioners. For clarity and mutual understanding, the terminology used throughout this research is defined as follows:

White-Collar Workers are wage earners who perform jobs which support the production floor or who work in service industries performing jobs not consisting primarily of manual labor.

Blue-Collar Workers are wage earners who perform repetitive, manual tasks in a factory where their work results in the production of tangible goods or products.

Information Workers are those white-collar workers whose jobs primarily consist of the handling of information.

Knowledge Work is work composed of activities which require a significant amount of cognitive ability, as opposed to skill; the knowledge worker is that information worker who not only deals with information as part of the job, but also produces it.

Measurement is the process of obtaining a value of a quantity in terms of a standard unit. It provides a vehicle for monitoring progress and setting quantifiable objectives.

Standard Time is the time for the "average" worker to complete a task using the "standard" method at the "normal" pace.

Target Time is the expected completion time of a task for which workers are expected to aim.

Performance is the degree of attainment of the desired results of an action or actions. It includes the attainment of quality results as well as productivity (Sink 1983).

Effectiveness is the degree to which a job fulfills its purpose.

Efficiency is the degree to which resource utilization is minimized to perform a job.

Productivity is generally defined as the ratio of output over input. However, this definition tends to be inadequate when referring to the knowledge worker because often the outputs are intangible or indefinable. Hence, a broader definition is required, one which not only includes efficiency but includes efficiency as it relates to performance and quality.

A yet broader definition is that productivity is the ratio of desired results to all resources consumed, or as defined by Stewart (1978) "the ratio of performance toward organizational objectives to the totality of input parameters". From these definitions, "productivity" does not exist operationally at the individual level. Although "worker productivity" is used consistently in literature, it is really a misnomer, especially when used with respect to the "knowledge worker". To quote Connell (1983) "When the term of productivity is applied to managers whose assignments call for the gathering of knowledge, the analysis of alternatives, and the making of choices, the contradiction in terms becomes apparent." Although much of the literature refers to productivity of the knowledge worker, it is a possible misuse of the

term. **Productivity** in this research refers to quantifiable quality output divided by input. **Performance** is considered only in that productivity is a subset of performance.

Quality is a degree of acceptability as defined by standards or objectives.

Quantification is the process of determining the number of countable units in terms of increasing or decreasing magnitude.

Timeliness is the degree to which results are produced on an acceptable schedule.

Work is the exertion of human effort for a specific purpose.

Background

The United States is undergoing a massive reorganization of work. We are moving from the "Industrial Age" into the "Information Age" at a pace which few could have forecasted. The impetus behind this transition is the demand for more accurate and timely information. A torrid pace in technological advancements in computers and communication equipment has resulted. Historically, technology advances have had a major impact on the economy of this nation. Technology changed this country from a farming nation into a goods-producing nation. Technological innovations, such as interchangeable parts (which enabled mass production), brought about an industrial revolution. As the land became more productive with less labor, the manufacturing industry

was growing and could absorb displaced farm laborers. Thus, the workforce was then dominated by blue-collar workers, and this group were the recipients of management efforts toward labor cost control and increased productivity.

Now, however, much of what was performed by the production worker is being performed by automated machinery with the aid of computers. As a result, the contribution of the blue-collar worker is diminishing while that of the indirect worker is increasing. To add to this changing composition of the workforce in manufacturing industries, there is a widespread increase in the number of service industries and thus an additional amount of workers who are not directly involved in the production of tangible goods.

Table 1 (cited in Gregerman, 1981) shows the shifts in the American workforce which have taken place from 1900 to 1986. It is apparent from this table that the white-collar worker has an ever increasing impact on this nation's economy. Thus, as it was vital that factory workers of the early 1900's consistently produce like products in the most economical manner, it is equally as vital to our economy today that knowledge workers consistently produce quality services in the most economical manner possible.

Table 1 indicates that nearly two-thirds of the American workforce are classified as white-collar workers. According to Denmark (1981), 60% of those white-collar workers are knowledge workers, and almost 75% of them work in service industries. Anthony (1984), identifies the standard classifications of the white-collar category as follows: clerical (36%), professional/technical (31%), managerial/administrative (21%), and sales (12%). If "knowledge workers" excludes clerical and sales persons, the remaining segment of workers approximately equals the percentage of all blue-collar workers (33%); and they incur over 50% of all labor costs.

Table 1
Changes in the Composition of the American Workforce

Percentage of Workforce			
Year	White-Collar	Blue-Collar	Farm
1900	17.6	44.9	37.5
1920	24.9	48.1	27.0
1940	31.1	51.5	17.4
1960	42.2	51.5	6.3
1980	50.9	46.3	2.8
1986	64.0	33.0	3.0

Source: Bureau of Labor Statistics [1980]

An indication of the importance of white-collar productivity, is noted by statistics cited by Denmark (1983), indicating in 1981, the U.S. productivity growth rate was +1%, blue-collar workers +6%, and white-collar workers -4%. It would appear then, that most of the productivity problem resides among white-collar workers.

While considerable progress has been made in increasing our knowledge of work in general, less has been made in the specific nature and measurement of white-collar work, particularly that area of white-collar work known as knowledge work. However, the management and control of knowledge workers are critical to this nation's economy.

This group of workers comprise a significant portion of the American workforce and incur the majority of labor costs. In fact, the failure to effectively manage these workers is the reason offered by many for the decline in labor productivity growth which this nation is presently experiencing.

The shift to a workforce predominantly composed of workers in indirect labor categories or in the service industry, along with the changing nature of all work due to technological advances, has created difficulties in defining, measuring and managing the work of all classes of workers. These difficulties are especially acute when

attempting to measure the productivity of the knowledge worker. It is imperative that answers be found which provide insight to and understanding of that segment of the workforce which has the greatest influence on our economy.

The work performed by knowledge workers differs from the work which traditionally has been considered measurable. First, it entails a significant amount of cognitive ability, as opposed to skill-based activities; secondly, it rarely produces a tangible output; and thirdly, the work is not patterned or effectively decomposable. Thus, techniques used for measuring blue-collar work may be inadequate for measuring knowledge work. As the literature reveals, the tasks performed by knowledge workers have not been fully defined; thus, effective techniques for measuring their contributions have yet to be developed.

Problem Statement

The working day on the production line is defined to the smallest detail. Those workers know what is expected of them, and there is a prescribed and known procedure for determining if they are completing their work in the accepted manner within the expected time. This is not the case for knowledge workers. The knowledge worker's

day has not been defined simply because the work is not fully understood. This understanding might come through measurement. In fact, it has often been quoted that:

"If you can measure that of which you speak and can express it by a number, you know something of your subject. But if you cannot measure it, your knowledge is meager and unsatisfactory."

Lord Kelvin

According to Lord Kelvin's premise, the failure to measure knowledge work indicates that our knowledge of it is extremely meager and unsatisfactory. It also indicates that the development of other work descriptors and prescriptions are inhibited. In fact, work measurement provides the foundation for determining the productivity of workers. Thus, without the knowledge afforded by work measurement, the determination of knowledge worker productivity is not possible. This is evidenced by the definition of productivity.

Productivity has been traditionally defined as the ratio of the total outputs over the total inputs. This definition assumes that both the inputs and the outputs are quantifiable. It implies that productivity is measurable and can be expressed as a meaningful number (an index). However, knowledge worker output often is not clearly definable nor easily quantified.

Historically, the quantification of productivity at the factory level was uncomplicated and straight forward. Outputs were the finished products that went out the door, while inputs were capital, raw materials, energy, equipment, and labor. All of these elements were unitized and "measured". In the case of labor, the predominant group was the "blue-collar" worker who was directly involved in the production of the finished product. The remainder was "white-collar", which was relatively small, and was added as overhead cost, typically at a percentage of production cost.

The quantification of productivity of the "blue-collar" worker at the individual level was also straight forward. Their finished products consisted of subassemblies, which consisted of sub-sub-assemblies, which consisted of parts. Because "blue-collar" costs were the predominant cost, the desire was to minimize these costs. Minimization could only occur if the time to produce a part could be measured and minimized. The time to produce a part at the individual level was determined by a work measurement technique such as time study or work sampling, to provide a "standard time" in which a "average" worker could complete a task while working at a "normal" pace. This enabled both inputs and

outputs to be unitized and measured so that productivity at the individual level could be quantified.

The quantification of productivity of the "white-collar" worker at the organization and the individual levels, however, is neither straight forward nor uncomplicated. The dramatic increase in the percentage of these workers suggests that their costs can no longer be simply categorized as overhead costs and allocated as a percentage of production costs. Some method of quantifying the "productivity" of these workers must be developed so that their costs can be controlled.

The quantification of "knowledge worker productivity" presents two difficult problems. First, the development of "standard times" is difficult because of nonrepetitive and dissimilar tasks; and secondly, "knowledge worker" tasks cannot be directly associated with finished products as "blue-collar" tasks can. Thus, either the inputs, the outputs, or both often cannot be quantified and used to produce productivity indices.

Typically, management "inputs" a quantity of "white-collar" employees to maintain a "level of performance". This is usually done without any measurement of the effort required to complete tasks and no knowledge of the expected time to complete them. Also, without a

quantifiable output at the individual and organizational levels, the number of units produced cannot be determined. Thus, a productivity index is not possible. One can only set goals and measure "performance" as a percentage of attainment of those goals. Several methodologies for doing this are being applied today, e.g. Management by Objectives.

What is needed then is a methodology that will determine an expected task completion time for knowledge work and associate each task completion time with a quantifiable output or "deliverable". It should conform to the standards procedure of the "average" employee working at a "normal" pace.

This research provides such a methodology. It permits the quantitative description, analysis, and measurement of knowledge work for the purpose of productivity measurement. The methodology includes a hierarchical structuring of work and determines the level at which work should be controlled based on the task duration (the level at which the work should be measured to provide feedback for the chosen level of control). It identifies the most appropriate measurement technique for the type of work in question. It also provides a means for determining how the target time should be calculated (as a factor of the amount and type of aggregation

required from the measurement level to the control or reporting level).

General Approach to the Problem

Productivity may refer to a single worker, an organization, a company, an industry, or even a nation. At these different levels of aggregation, the concept as well as the measurement schemes change. This research concentrates on the productivity of a single worker, specifically, the knowledge worker. This choice is based on the premise that as the productivity of the individual workers improves, so will that of the higher levels.

The approach taken involves three phases: (1) information gathering, (2) development, and (3) testing and refinement. The first phase consists of a literature review and an industry survey. During the second phase the structuring and measurement systems are developed; and the third phase involves the application of the measurement system at two local companies.

Organization of the Dissertation

This research is presented in five chapters, including the introductory chapter. Chapter II, "Literature and Industry Survey," reviews the literature

coverage of white-collar and knowledge worker measurement and presents the results of an industry survey. The third chapter, "Development of the Measurement Methodology," presents a methodology for structuring and measuring knowledge work, as well as developing the target time for determining productivity. Chapter IV, "Application of the Measurement Methodology," presents two sets of data to which the steps of the methodology were applied, and discusses the results of these applications. The last chapter, "Summation," summarizes the research, discusses conclusions concerning the methodology presented, and presents some recommendations for possible expansion.

CHAPTER III

LITERATURE AND INDUSTRY SURVEY

Introduction

Literature and industry surveys were conducted to reach a consensus on the identity of the knowledge worker and the characteristics which distinguish knowledge tasks from manual tasks; to identify work classifications based on task characteristics; to identify methods which have been applied successfully in measuring blue-collar work for the purpose of determining if any of those methods could be used or adapted to measure knowledge work; to identify the problems of measuring the productivity of knowledge workers; and to assess approaches being applied in industry or suggested by other research.

Measurement

As previously stated, measurement is the process of assigning a value or number to an object. However, this assignment is usually done according to some rule. The applied scale is that rule or procedure. The acceptability of a measurement is based on such concerns as its appropriateness, reliability, consistency, and

accuracy (Davison, 1988). These concerns are also affected by the purpose for the measurement.

The applied scale is also called the "level of measurement" because it classifies data according to four levels of increasing complexity:

1. Nominal,
2. Ordinal,
3. Interval, and
4. Ratio.

When numbers are arbitrarily assigned to represent different characteristics of a given variable, those characteristics are at the lowest level of measurement, the nominal level. Ordinal level data are ordered data. The numbers assigned to the items within a variable now have numerical significance and indicate their rankings relative to one another. Interval level data not only indicates the ordering of items within a variable but the interval between those items, indicating that the arithmetic difference between the items is meaningful. With a ratio scale, in addition to having an order property, a unit of measurement, and a meaningful arithmetic difference between items, there is also a fixed origin or zero point.

The level of measurement chosen for a variable will affect the types of analyses which can be conducted, and

thus restrict the information which might be obtained. Likewise, the purpose for the measurement will affect the level. For example, job analysis systems predominantly use ordinal scales to obtain information about employees for human resource management. Exceptions are those systems which use amounts of time or percent-time-spent on tasks; in such cases, measurement may be on an interval scale with equal units.

Another issue of measurement is the dimensionality of chosen scales, whether they should be unidimensional or multidimensional. A relative time-spent per task scale is unidimensional because it only describes one aspect of the activities. A multidimensional scale, such as that used by Hemphill (1959), measures a number of variables. Of the two, unidimensional scales are more straightforward to interpret; however, they do not provide as much information.

Instead of a single measurement for each task performed by a worker, it may be preferable to provide for at least two for each task: a descriptive measurement such as part of the job, and an evaluative rating such as importance or complexity. In fact, there is historical precedent for such multiple ratings in the Air Force task analysis program (Morsh and Archer 1967) where ratings were obtained for both relative time spent per task and

the difficulty of the task. This approach has worked well in developing specific position descriptions and generic clusters of jobs (Morsh 1964, Christal 1974, McCormick 1976).

These different levels and dimensions of measurement are used in the techniques which provide structured approaches for determining values of time standards for all types of work.

Work Measurement Techniques

Workers have been measured since the late 1800's. Even then, management recognized the need for a standard so that work could be effectively managed. The measurement provides that standard. Traditionally, however, work measurement tools and techniques have been designed for and applied to workers who produce tangible products or workers with well-structured jobs consisting of repetitive tasks. Though new techniques have been developed through the years, none have come to the forefront which might be applicable for measuring workers performing creative, open-ended, knowledge-based work -- as noted below.

Frederick W. Taylor, "the father of industrial engineering and scientific management," in 1883 developed a systematic approach to the management of employees by

organizing and defining work tasks, which led to methods improvement. He divided work tasks into their individual work elements so that they could be studied separately, giving rise to motion study.

Although Dr. Taylor's approach was sound and well structured, its rigidity, which stemmed from a lack of concern and tolerance for employees, along with management's eagerness to realize profits, gave the approach a negative reputation. So negative, in fact, that labor began to call its practitioners "efficiency experts."

Frank and Lillian Gilbreth extended and softened Taylor's work in 1912. He was an engineer, and she a psychologist -- together, they developed a sound and objective approach tempered with understanding of the factors that motivate employees. They refined methods study to an exacting discipline by breaking down complex tasks into basic elements of motion. Rather than force employees into the pattern of a job, the work was reorganized around the needs of the employee.

Scientists and engineers later came to realize that methods study and time study were not distinct or alternative approaches to measuring employees, but rather were inseparably linked. Jobs first needed to be studied to determine the elements involved in their execution and

those elements could then be studied to develop an expected time of completion. The combination of the works of Taylor and the Gilbreth's became known as time and motion study. This system became formalized in the 1930's and 1940's but still had certain disadvantages which led others to develop even more effective techniques for the quantification of work.

The next major development, work simplification, occurred in 1930 and was originated by Allan Mogensen. He defined work simplification as the organized application of common sense to finding better and easier ways of doing every job, from eliminating wasted motions to rearranging the work place. Several techniques, developed primarily to overcome the stigma of the stopwatch time study or to extend the work of the Gilbreths by developing predetermined standard times for job tasks, were developed and used in this country in the 1930's. Among these techniques (in chronological order of their development) are motion-time-analysis (MTA) by Segur, the Work Factor System by Joseph Quick and other RCA engineers, and Motion Time Standards (MTS).

These systems led the way for the development of what has become the most widely used predetermined time system in the world, methods-time-measurement (MTM) which was developed in the mid 1940's by H. B. Maynard and

other engineers at Westinghouse Electric Corporation. Later, work sampling, developed by L. H. C. Tippet in England in 1934, was introduced in this country by Ralph Barnes in 1957 to remove some of the pressure from individual employees by studying groups.

A number of standard data systems were developed from basic MTM for application in the office environment; however, most of these systems are for clerical work only. They are, in chronological order, Master Clerical Data (MCD), 1958; Clerical Standard Data (CSD), 1960; Advanced Office Controls (AOC), 1973; and Methods-Time-Measurement -- Clerical (MTM-C), 1978.

Since this time no significant new developments for measuring other workers, particularly knowledge workers, have been reported.

The Knowledge Worker

Knowledge workers are distinguished from other classes of white-collar workers by the large percentage of their work which requires the application of knowledge. The knowledge worker creates, designs, develops ideas, and exercises independent judgment in performing job tasks. This is not to say that knowledge workers never have to apply skill, a learned ability, but that the majority of their work is based on using

knowledge. The knowledge worker is distinguished from other classes of workers by the following characteristics of the jobs performed:

1. Nonrepetitive job tasks;
2. Almost total authority in matching individual work methods to the various job tasks assigned;
3. The output is at best difficult to quantify -- thus, it is difficult to measure productivity with the classical methods;
4. There is often a long time span between the job activity and the performance or results feedback;
5. The "production rate" is dependent upon the complex interactions among intelligence, creativity, and environmental influences;
6. How well a job is done may depend on how skillfully new technologies are applied;
7. Frequently, substantive numbers of people, both inside and outside the organization, are affected by the work; and
8. The work tends to be interdependent -- most often it is performed by teams.

These characteristics have been described by Gregerman, Ruch, Lehrer, Porter, Packer, Kwon, and others. Hence, there seems to be a general consensus on who the knowledge worker is in the workplace.

Knowledge workers may be found in all organizations and at all levels in a company. They are found in manufacturing companies as support personnel or indirect labor, but they are in service firms and government at a higher percentage of the workforce. They are found in a variety of capacities throughout an organization. Ruch (1982) identifies these different areas as: (1) Management, (2) Support, (3) Supervision, (4) Marketing, and (5) Service Producers.

Some of the tasks performed by knowledge workers as described by Kwon, LeBouef, Porter, and Ruch involve sending mail; using the phone; attending meetings; document creation; filing or retrieving information; scheduling; analyzing data; and reading. Not all of these tasks are knowledge tasks, but no knowledge worker performs jobs consisting exclusively of knowledge-based tasks. Identifying and understanding the tasks performed by workers is the foundation of work classification schemes.

Work Classification Systems

In response to the Depression of the 1930's, research in studies of work concentrated on the development of a classification system for jobs. The purpose of such a system was to enable the government to

assist in the identification of job openings and their requirements, for the referral of qualified applicants. This need ultimately resulted in the U. S. Employment Service (USES), which inventories both jobs and available manpower. A major by-product of this agency was a creation of a standard taxonomy of jobs which was later published as the Dictionary of Occupational Titles (DOT) in 1939 (Shartle 1959).

Another development of the late 1930's was a rapid growth in government and industry which created many new jobs in managerial and service-oriented areas of work. Interest in these new types of positions sparked research concerned with the identification of their basic characteristics. Thus began an earnest effort among researchers and government agencies to study the types of tasks performed in a variety of jobs.

Flanagan's research (1951) was concerned with the identification of basic dimensions of executive and scientific jobs; he studied the requirements for success in a variety of engineering and scientific jobs. The results indicated eight performance dimensions of such positions. An analysis of those dimensions indicates that these positions are primarily concerned with the gathering, processing, and application of information. Another dimension indicated is supervision of others.

Thus, if those eight dimensions could be reduced to three, they would be (1) information processing, (2) supervision of others, and (3) responsibility. Following are the eight as listed by Flanagan.

1. Formulate problems and hypotheses,
2. Plan and design investigations,
3. Conduct investigations,
4. Interpret research results,
5. Prepare reports,
6. Administer research projects,
7. Accept organizational responsibility, and
8. Accept personal responsibility.

Rothe (1951) studied the operations involved in the work of supervisors. His rational analysis of their tasks essentially indicated a sequence of problem-solving tasks which are common to most decision making jobs. This analysis resulted in the identification of six basic operations:

1. Plans activity,
2. Decides,
3. Organizes groups,
4. Communicates the program to the organization,
5. Leads the organization toward the goal, and
6. Analyzes progress toward the goal.

Several of these operations are identical or very similar to the basic requirements which were previously identified by Flanagan. Rothe's analysis also introduced the concept of leading as a legitimate activity of the supervisor.

Williams (1956) used the critical incidents technique to study executive performance. He identified six critical tasks of executives:

1. Planning, organizing, and execution of policy;
2. Relation with associates;
3. Technical competence;
4. Coordination and integration of action;
5. Work habits; and
6. Adjustment to work.

Some of these, such as planning and technical competence, have direct analogues in Flanagan's earlier study.

Palmer and McCormick (1961) performed a factor analysis on 250 jobs in a large steel producing mill. Their sample consisted of both blue-collar and white-collar positions. A principal components analysis of the basic factor intercorrelations yielded four higher order orthogonal factors which included:

1. General decision making and mental activity,
2. Differences in physical activity,

3. Differences in communication activity, and

4. Differences in quantitative activity.

This work is important in its recognition of the decision making area as a key component differentiating levels of work. Also, the authors concluded that work tasks "can be identified or measured and that the variety of human work tasks may be organized with greater simplicity and economy in terms of a smaller number of relatively independent dimensions (Page 274)."

Helm (1961) used a factor analytic methodology to define the positions of engineers at General Electric and a variety of other companies. Subsequently he found that the factor structure underlying engineering positions could be reduced to five dimensions:

1. Estimating costs;
2. Developing and utilizing people;
3. Drawing, calculating, and reporting;
4. Persuading or negotiating with others; and
5. Originating, developing, and testing ideas.

Mahoney, Jerdee, and Carrol (1963,1964) derived eight management functions from a functional analysis of the performance of incumbent managers (452 managers in 13 companies) and measured those functions in terms of the proportion of time spent doing each type of task. Those

functional dimensions of managerial performance
identified include:

1. Planning,
2. Investigating,
3. Coordinating,
4. Evaluating,
5. Supervising,
6. Staffing,
7. Negotiating, and
8. Representing.

A job analysis method which came into fruition in the mid 1960's was the Functional Job Analysis (FJA) system developed by Fine (1967). This approach had been evolving for a number of years in the USES and is used in its DOT. This rationally and empirically derived system classified jobs in part by rating the orientation toward three worker functions: Data, People, and Things. Each position is assessed in terms of hierarchies of each of these worker functions, using scales of 6, 7, or 8 degrees, as specified by Fine. These theoretical job functions have both strengths and weaknesses. On the positive side, the arbitrary selection of the three worker function hierarchies eliminates the greater variability in factors identified in earlier research.

On the negative side, Fine's construction of the artificial vector space might be considered an oversimplification of the complex nature of the world of work. For the purpose of classifying jobs, however, it is quite useful. In fact, it lends itself to that end. Thus, although this construct might not be exhaustive, it is clearly applicable for analyzing jobs. Also, it offers a structure which facilitates the comparison and categorization of jobs.

McCormick, Jeanneret, and Mecham (1969,1972) developed a major job analysis system: the Position Analysis Questionnaire (PAQ), which was used to study 536 jobs. The resulting responses were submitted to a principal components analysis, with five general dimensions resulting:

1. Having decision making/communication/social responsibilities;
2. Performing skilled tasks;
3. Being physically active/related environment conditions;
4. Operating vehicles/equipment; and
5. Processing information.

A marked advantage of this system is the quantification of job information, in terms of job dimension scores.

Also, like Fine's FJA system, the PAQ provides for the analysis of all types of jobs.

A critical issue is the identification of an appropriate set of variables (components, functions, factors, etc.) which would have a high commonalty for the knowledge worker positions. Review of the literature reveals that no single, consistent set of variables has emerged.

No one methodology can be used exclusively to identify the relevant set of dimensions, since no one system has proven totally acceptable in the past. Neither is there much agreement on the optimum number of dimensions which should be considered.

Mitchell (1978) organized the names of all variables identified in the literature which he reviewed into similar constructs and clustered them into discrete areas. Table 2 is an update of his organization with the addition of results found in the literature since his publication.

These constructs seem to cluster themselves into three different classes. Constructs one through six appear to be generic types of activities which are involved, to some degree, in most white-collar positions. The last three constructs are not activities. Responsibility is more of a work parameter than an

Table 2

Identification of Relevant Constructs

Generic Construct	Sources - Specific Constructs
Planning/Scheduling	Flanagan 1951 - Formulate problems & hypotheses; Rothe 1951 - Plans activity; Williams 1956 - Planning; Hemphill 1959 - Long range planning; Helm 1961 - Plans use of materials; Mahoney, et al 1963 - Planning.
Processing of Information & Ideas	Flanagan 1951 - Interpret research results; Helm 1961 - Drawing & calculating, Developing testing ideas; Fine 1967 - Data function; McCormick, et al 1972 - Information processing.
Making Judgements	Rothe 1951 - Decides; Palmer & McCormick 1961 General decision making; McCormick, et al 1969, 1972 - Decision making.
Communicating	Flanagan 1951 - Prepare reports; Rothe 1951 - Communicates; Helm 1961 - Writing technical material; McCormick, et al, 1969, 1972 - Communication of decisions/judgments, Job-related information exchange.
Interpersonal Activity/	Rothe 1951 - Organizes group, Leads; Williams 1956 - Relations with associates; Hemphill 1959 - Supervision - human, social and community affairs; Helm 1961- Customer service; Mahoney et al - Coordinating, Supervising, Representing; McCormick, et al - Supervisor/subordinate relations.
Technical Activities	Williams 1956 - Technical competence; McCormick, et al 1969, 1972 - Performing skilled activities.
Responsibility	Flanagan 1951 - Personal & Organizational Responsibilities; Hemphill 1959 - Power and authority, Internal business control, Preservation of assets; Fine 1967 - Level of function as responsibility estimate; McCormick, et al 1969, 1972 - Responsibility.
Personal Development	Williams 1956 - Technical competence; McCormick, et al 1969, 1972 - Education level, Job related experience, Training.
Personal Qualities	Williams 1956 - Adjustment to work; Work habits; Hemphill 1959 - Personal demands.

activity; and the last two relate to aspects of the worker rather than of the work.

A closer look at the six constructs in the class relating to the work reveals a clustering among them. The first three relate to information or Data; the next two concern People; and the sixth refers to the use of Things. This supports Fine's assertion that all work can be described in relation to Data, People, or Things.

Categories of Work

The lowest level of measurement for an entity requires first that the entity be clearly defined. Thus, before work of any kind can be measured, the distinctions among the various types of work must be delineated.

Beruvides and Sumanth (1987) define three distinct types of work: blue-collar, white-collar, and knowledge. Their classification scheme is depicted in Table 3.

They distinguish these work types according to four major characteristics: nature of work, tangibility of outputs, tangibility of inputs, and the degree of discretion used in performing tasks.

Figure 1 is an expansion of these work categories as described by Beruvides et al. (1988). They identified regions of intersection which expand the categorization

of work to encompass all conceivable work. He calls his scheme "the Universe of Work," and it is shown in Figure 1. The universe of work has at least seven distinct areas in which work can be categorized. These overlaps account for the jobs which are not categorically one of the three primary classes.

Table 3
Characteristics of Work Types

Work Characteristic	Type of Work		
	Blue Collar	White Collar	Knowledge
Nature of Work	Manual or Physical	Any Nature	Any Nature
Outputs	Clearly Definable (Tangible)	Mainly Tangible with some intangible factors	Some tangible factors, but mainly intangible
Inputs	Clearly definable and directly influential in output	Definable and directly influential in output	Not clearly definable and can be (not necessarily) influential in output
Degree of Discretion	Practically None	Little or None	Very High

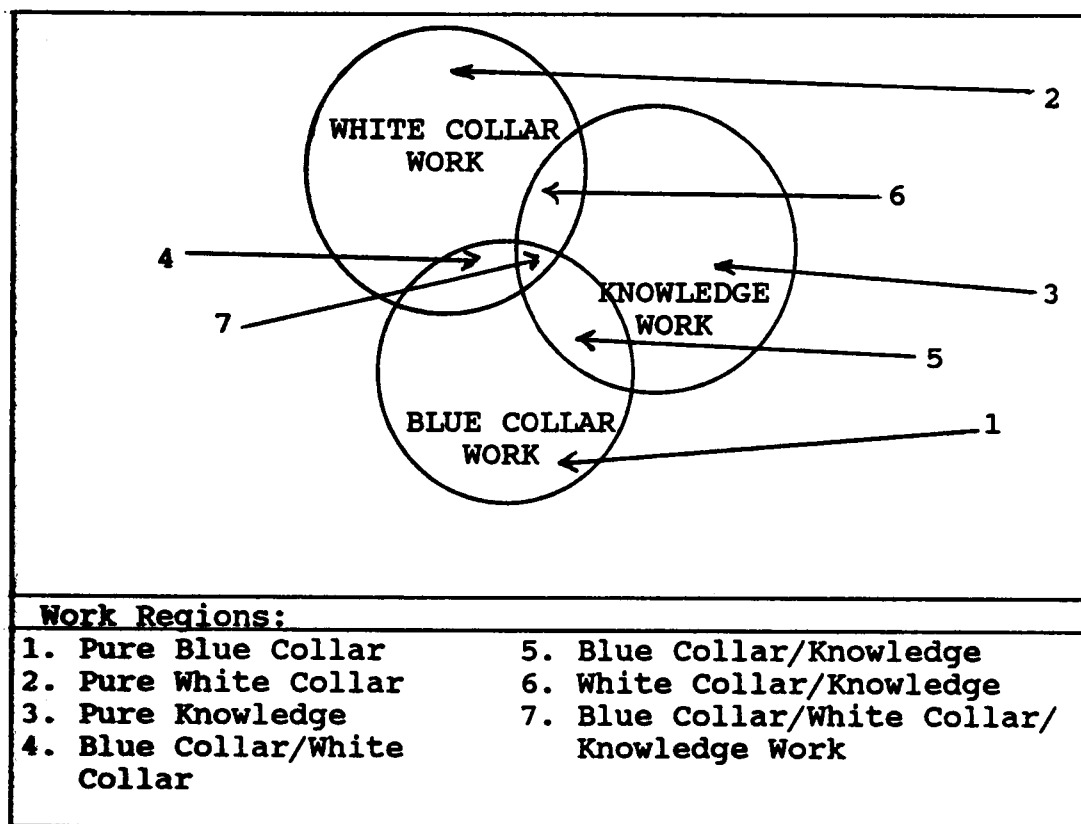


Figure 1. The Universe of Work

Measuring Knowledge Worker Productivity

Approaches

Productivity generally is considered to be the ratio of output to input. Measuring one or both of these quantities becomes complicated when the job involves a significant amount of knowledge work. The reason is that knowledge work rarely produces the firm's output, instead it's results contribute something that causes or permits

output to increase by enough to cover the input of the worker. Thus, the numerator should be defined as a contribution, focusing attention on the nature of the work and its relationship to organizational goals.

According to Packer (1983) there are four basic approaches to measuring the effectiveness of knowledge workers: informal; single indicators; multiple indicators; and weighted composites of indicators. Lehrer (1983) and Young (1980) class the approaches into three broad categories: informal; semiformal; and formal. The informal approaches are purely subjective estimates and include historical data, short interval scheduling (SIS), and wristwatch time studies.

The Semiformal approaches include work sampling and time-ladder studies. The formal techniques include time studies, performance leveling, and predetermined time studies. As these approaches progress from informal to formal, accuracy and consistency of standards are gained, and the degree of control which can be achieved is increased. The single indicator, multiple indicators, and weighted composite approaches described by Packer could be either semiformal or formal, depending on the purpose for measuring.

All of these approaches have certain disadvantages. The single indicator approach presents a picture and may

lead to the improvement of only one aspect of performance. The multiple indicators approach overcomes this shortcoming by using a set of indicators simultaneously, but may encounter problems of scale among the various indicators. The weighted composite of indicators overcomes the problem of scale, but may have problems due to the intercorrelation of indicators.

Other difficulties arise when measuring knowledge work. These problems are due primarily to the nature of the work itself. They are discussed in the next section.

Difficulties

Attempts to measure and control knowledge worker activities to the same degree as factory workers have generally been unsuccessful. The reasons as described by Harris and Vining, Liker and Hanconk, Frederiksen, Packer, Gregerman, Ruch, Lehrer, and others are many:

1. Knowledge work is not patterned or sequential.
2. Knowledge worker efforts are usually less effective if sub-divided because of lengthy task completion cycles and activity complexity.
3. Too much detailed control over knowledge workers tends to stifle creativity.
4. Outputs are of a less physical nature and are difficult to define. Generally the knowledge worker

contributes to the output through the design or improvement of the processor through providing a support service to the production activity. Defining the nature, the value, and the unit of measure of this contribution has proven to be a difficult task.

5. Attempting to define the tasks usually results in omitting important job elements, making measurement errors, and unpredictable occurrences.

6. It is difficult to match inputs and outputs within a time frame. The resources currently consumed by the knowledge worker may not show results until several periods later. In many cases, the contribution made in the current period affects the achievable results in all subsequent periods.

7. It is difficult to measure the quality aspect of the knowledge worker's output.

8. For the knowledge worker, productivity not only measures the efficiency but the effectiveness. Hence, it is not only important that resources are properly applied so that a job is done well, but a job must accomplish its stated purpose.

In spite of these difficulties, various companies have begun to develop measuring schemes to meet their individual needs -- some company-wide, others for specific groups.

Industry Measurement Approaches

The literature review revealed a number of references which describe measuring schemes used in industry. A number of them deal with applications in specific service industries such as banking (Anthony and Steve Stewart), transportation (Philbin), insurance (Gass), and hospitals (Ferderber, Kulonda, and Hancock and Chan). Some of them examine approaches adopted by local, state, or federal government (Bryant and Field; Engwall; Goode and Meier; Mark (December 1972); and Monte-White and Eaton).

Some of the literature is devoted to discussing the "office of the future." These articles range from general descriptions of the hardware and how it is used to increase productivity to how the hardware can be used to measure productivity (Abraham; Bovino; Connell; Kwon and Hamilton; Popple; Rosen and Fielder; Schlar; Udler and Monte-White; and Young).

An industry survey of Fortune 500 companies was completed in March 1988 (The letter soliciting information is in Appendix A). It revealed several company-wide programs for measuring or improving white-collar productivity. Summaries of the most significant follow:

1. International Harvester

Managers in each area are asked to survey their departments to establish job definitions and performance standards for individuals, work groups, or departments. These definitions and standards then become the targets for productivity improvements in the form of staffing changes, changes in capital equipment, or other changes in the process. It is based on the premise that those directly responsible for the work are in the best position to define and analyze its productivity. This procedure is used for both blue-collar and white-collar departments.

2. Cities Service Company

This company uses a similar approach: they begin with a definition of the job to be done and how that task relates to the entire company. From this, measures are devised. Some of these measures are Sales/Employee; Profit per Employee; and Pieces of Correspondence Processed per day.)

3. IBM

The procedure pioneered by IBM in the mid 1960's is called Common Staffing Study. It is based on the identification of discrete activities or tasks performed as part of a particular job function. The steps involved are:

a. Define functional areas and the activities of each area.

b. Establish performance indicators for each activity.

c. Collect and analyze data with respect to the indicators.

The results are interpreted and used to identify areas of opportunity for productivity improvement; track indirect labor productivity; establish manpower requirements; or other management purposes. The ultimate purpose of Common Staffing, however, is to indicate trends, not to develop performance standards.

4. Hughes Air Craft

Hughes has addressed the problem of measuring the performance of knowledge workers in research and development by developing a number of quantitative and qualitative indicators to monitor the performance of individuals and the organizations. The result of their studies on this issue is found in the book R&D Productivity, published in 1978. The techniques they recommended are work sampling, analysis of productivity ratios and trends, and assessment of patterns of success and failure in technical, cost, and schedule performance.

5. The Extensior System

This measurement system was presented in the literature by Robertson, who is the Vice President of the Extensior Company. It is a system developed in Scandinavia in the 60's, but has been marketed in this country only since 1973. It is a dimension-oriented, automated work sampling procedure in which the individual enters his activity at certain intervals in a small data-gathering device located at his work station. This system allows the quantification of the behavior dimension.

6. XEROX

XEROX uses a modified work distribution analysis technique to study its various organizations. The procedure includes the development of activity and task lists by interviewing managers and employees; the employee then records daily tasks to develop distribution data on where time is spent; then, the 80/20 rule is used to identify which activities give maximum return on profit and which activities need improvement.

7. Seattle First National Bank

This application was presented in the literature by Anthony. This bank uses a straightforward, traditional process. The tasks being performed are examined and studied to see if the work can be done more

easily. Next the work is measured. Then data is accumulated on the area's mission, the functions, the activities, the steps, and some-times even the motions; and on the volume and times for professional and technical staff from time diaries, estimates, work sampling, or direct observations. After compiling the data, it is analyzed to determine total time, total units, total time per unit, and the total time percentage for each task. Direct observations are then performed on the most significant tasks to determine if the data should be leveled. The process is then modeled by extending the results into an annual profile that takes into account seasonal activities.

8. Southern Company Services

The Southern Company Services (SCS) provides engineering and technical services to utility companies in Georgia, Alabama, and Mississippi. In 1979, SCS began a formal productivity improvement effort in its engineering division. The five functional group managers developed measurement indicators for their respective areas, and began to use them to measure the performance of their engineers.

Summary

The need to measure and control knowledge work is recognized by industrial practitioners and academic researchers. The problem in doing so, however, is one of overcoming the difficulties resulting from the nature of the work itself. This research proposes, however, that these difficulties can be overcome by applying known and established work measurement techniques and improving the measurement to account for the peculiarities of the work itself -- particularly, those aspects of the work thought to be unmeasurable yet known to be important to the time.

A description of the methodology being proposed is described in Chapter III and explained with sample applications in Chapter IV.

CHAPTER III

DEVELOPMENT OF THE MEASUREMENT METHODOLOGY

Introduction

To determine productivity, one must 1) know how work units measured fit into the heirarchy of all work performed, 2) define what the work unit to be measured is, 3) have a work-unit count, and 4) have a standard or target time (the expected time for an average person to complete the work unit when working at a normal pace). The approach for satisfying these requirements in the measurement of productivity for manual workers has long been determined. A new approach must be developed for knowledge work.

The methodology presented in this chapter provides guidelines for the development of 1) a heirarchial structure of work required to achieve corporate end-goals, 2) appropriate work-unit definitions which facilitate identification of "what is to be done", 3) specifications for what is to be counted (work-units), and 4) standard or target times, or the improvement thereof. Thus, it provides an improved approach for determining expected completion times for knowledge work-units previously considered unmeasurable.

It is often imperative to know how much productivity can be expected from workers or how long certain tasks will take. In the case of the knowledge worker, these time predictions are often required of tasks never before performed or at least not performed by the currently planned method. Even in situations where a standard or target time exists or has been approximated, the question remains whether it is appropriate. Other questions might also surround this standard and create uncertainty with regard to its application. These might include: How does it relate to other standards which might be determined? What factors affect the performance and the time required to complete a work-unit? Could it be improved and, if so, by what means?

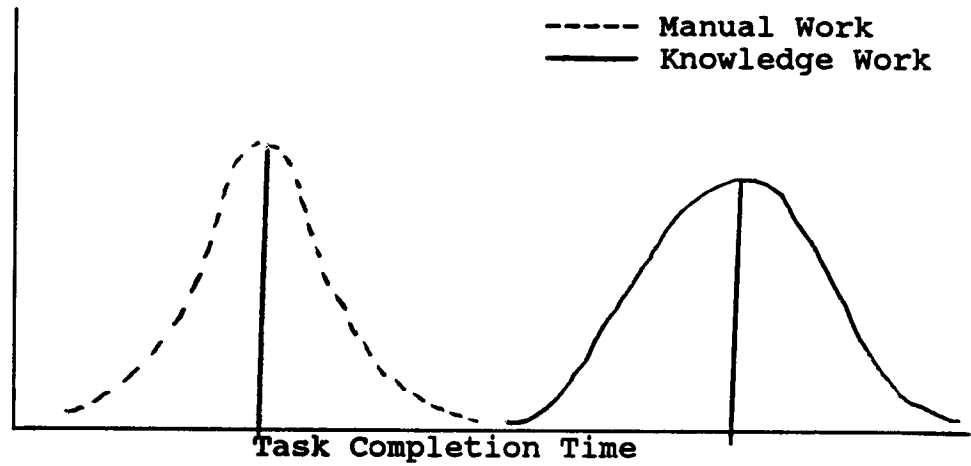
The methodology developed in this chapter provides answers to many of these questions. It provides guidelines for (a) structured analysis of the work to be performed; (b) selection of the most appropriate technique to measure the work, given its characteristics; (c) determination of the factors which affect the time to complete the work; and (d) calculation of the target time which accounts for factors previously omitted in traditional methods for determining standard times. Thus, this methodology provides an approach for determining expected completion times for work-units

previously considered unmeasurable, as well as an improved approach to traditional methods of developing time standards.

The steps of the methodology are developed to address specific problems in measuring knowledge work. First, the work structuring addresses the problems of downward differentiation of the work and upward aggregation of the measurement results. The process for selecting the measurement technique addresses the differences in the characteristics of knowledge work and those of work for which existing techniques readily apply.

Last, the process for determining the target time addresses the need to identify and reduce the wide variability found in completing knowledge work. Such wide variability in completion times of like or similar tasks is rarely found in manual work because of its repetitive nature. A comparison of the distribution and spread of completion times of both kinds of work is presented in Figure 2a, while 2b demonstrates how the computed target completion time tends to reduce the variability of expected knowledge work completion times due to the inclusion of parameters previously omitted.

2a. Comparison of Variances



2b. Effect of Target Time on Knowledge Work Variance

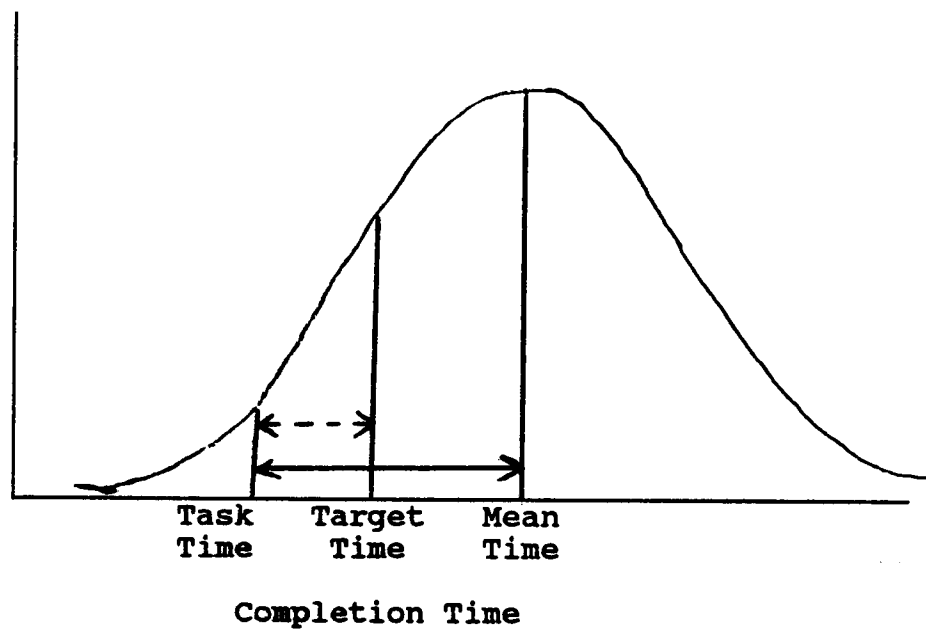


Figure 2. Variability in Knowledge and Manual Work

The structuring involves the decomposition of the work into its constituent units of completion to determine where the work should be measured and at what point control should be exercised. It also reveals the object, output, or recipient of the work for purposes of classification.

The results of the structuring provide input to the next step of determining the most appropriate measurement technique for the type of work in question. The chosen technique provides a time which must be further improved to obtain a target time for the completion of the work at hand. This accounts for the subtle differences in the work at hand and the work upon which the measurement time was based.

This methodology differs from other work measurement systems in that it not only accounts for those "loading" factors which can be counted as output or features of the output which might affect the time, but it also accounts for those "parameters" about the work itself which might affect the time. These parameters may either be tangible or intangible, but in any case, the methodology provides a means of measuring them. The specific characteristics of the methodology are described in the remainder of this chapter.

HEIRARCHIAL STRUCTURE OF WORK

The Work Structuring

Knowledge work has been considered nonreceptive to the industrial engineering philosophy of breaking work down into its basic components for work measurement purposes. Manual work, on the other hand, readily permits downward differentiation of work corresponding to lower assemblies of the product produced (product, sub-assemblies, components, parts, etc.) and the upward aggregation to product lines. In the past white-collar costs were simply added to "direct" manual costs as a percentage of overhead. Since white-collar costs dominate today, a new heirarchial structuring of work is necessary so that white-collar (including knowledge) costs can be controlled. The downward differentiation of work permits identification the measurable unit of the work and the base from which the upward aggregation of the measurement results might begin. The upward aggregation of the measurement results allow feedback for controlling the work at any level.

This philosophy is based on the premise that the work performed in a job should contribute to the accomplishment of a higher end or goal, and that all jobs are composed of constituent units which help attain that

goal. These parts have traditionally been identified as shown in Table 4.

This structure, offered by Mundel (1983:34), divides work into eight sub-units. The lowest three are associated with the activity of the individual, while the remaining five describe the physical outputs (products) expected as a result of the activity of an individual or group of individuals. Thus, this structure does not consistently aggregate the units of work to corporate end goals, but rather starts off doing so and then at the fourth level begins to associate the work with various levels of physical product assemblies.

This structure, however, is not applicable for knowledge work because knowledge work seldomly results in a physical product as does manual work. A structure which is more applicable for describing knowledge work is presented in Table 5. The significant differences in Table 4 and Table 5 are:

1. At level 1, Table 5 recognizes mental behavior as well as physical.
 2. At level 4, Table 5 aggregates tasks to jobs instead of associating them with products.
 3. At level 5, table 5 aggregates jobs to mission instead of associating them with groups of outputs.
- Likewise, aggregations to levels 6, 7, and 8 are similar.

Table 4

Definitions of Orders of Work Units (Mundel)

NUMERICAL DESIGNATION	OUTPUT NAME	DEFINITION
8th Order Work-Unit	Results	What is achieved because of the outputs of the activity.
7th Order Work-Unit	Gross Output	A large group of end products or completed services of the working group.
6th Order Work-Unit	Program	A group of outputs or completed services that are part of a 7th order work unit.
5th Order Work-Unit	End Product	A unit of final output; the unit in which a program is quantified.
4th Order Work-Unit	Intermediate Product	A part of a unit of final output.
3rd Order Work-Unit	Task	Any part of the activity associated with the performance of a unit by an individual or crew.
2nd Order Work-Unit	Element	The activity associated with the performance of part of a task.
1st Order Work-Unit	Motion	The performance of a human motion.

Table 5

Broader Definitions of Orders of Work Units

NUMERICAL DESIGNATION	OUTPUT NAME	DEFINITION
8th Order Work-Unit	Global End	What is achieved because of the outputs of all activities.
7th Order Work-Unit	Intermediate Goal	The achievement of strategic goal components by a division.
6th Order Work-Unit	Program	The achievement of tactical goals by an organization.
5th Order Work-Unit	Mission	The achievement or output of a work group.
4th Order Work-Unit	Job	The achievement of part of the end result by an individual.
3rd Order Work-Unit	Task	A natural unit of a job.
2nd Order Work-Unit	Element	Functional unit of a task.
1st Order Work-Unit	Behavior	The performance of a human behavior (physical or mental).

In fact, all of the levels in Table 5 are truly representative of work differentiation/aggregation. These levels are applicable for describing the general nature of all types of work - whether that work provides a tangible product, an intangible service, or no tangible output at all.

The levels of work shown in Table 5 represent a hierarchy in which each level, with the exception of the lowest, is composed of all the levels below it. Thus, data gathered at a lower level may be aggregated upward to provide meaningful information to a higher level. This differentiation/aggregation is particularly necessary when developing expected completion times for knowledge work because of the extreme variation in task completion times. For example, suppose a computer systems organization has delegated responsibility to "design computing systems". To design a given computing system could require one individual for hours or a team of analysts for years. Thus, "Design computing system" would be a task for the individual whereas, "write implementation plan" might be a task for one individual of the team. The "heirarchial structure" approach, then, permits downward differentiation of work until an appropriate level for measurement is found. Likewise, it permits upward aggregation of all work to corporate end goals.

Work-Unit Identification

A broader view of this heirarchial structure shows its contribution in developing an identification of an appropriate measurable work-unit. A work-unit must be an

identifiable element of work performed and have an object that can serve as a unit of count. The application of heirarchical structuring breaks work down into succeeding lower levels. A system of classification must now be developed to permit determination of an appropriate unit of work for measurement purposes. Since the primary purpose for classifying objects is to describe the structure and relationships of their constituent parts and to simplify these relationships in such a way that general statements can be made about the resulting classes, it would follow that the primary purpose for classifying work is to describe its structure and the relationships among its components so that general statements might be made about the different classes of work, particularly , statements which identify their results and their nature. Thus, a work classification scheme leads to a solution of the problem of what to count when measuring knowledge work and how to count it.

The classification scheme to be developed provides a structure so that statements can be made about applicable measurement techniques for each class. The basis of this system is the worker functions as defined in the Dictionary of Occupational Titles (DOT). The worker functions are based on the premise that every job requires a worker to perform in some degree with Data,

People, and Things, and that the involvement with each of these can be expressed as a hierarchy. That hierarchy is presented in Figure 3.

4th Digit DATA	5th Digit PEOPLE	6th Digit THINGS
0 Synthesizing	0 Mentoring	0 Setting Up
1 Coordinating	1 Negotiating	1 Precision Working
2 Analyzing	2 Instructing	2 Operating/Controlling
3 Compiling	3 Supervising	3 Driving/Operating
4 Computing	4 Diverting	4 Manipulating
5 Copying	5 Persuading	5 Tending
6 Comparing	6 Speaking/ Signaling	6 Feeding/Offbearing
	7 Serving	7 Handling
	8 Helping/Taking Instructions	

(Definitions for these functions are in Appendix B.)

Figure 3. DOT Worker Functions

In the DOT, a job's relationship to Data, People, and Things can be expressed in terms of the lowest numbered function in each category. These functions taken together indicate the total level of complexity at which the worker performs and provides standard terminology for use in summarizing what a worker does. Thus, they are being used in this study as a basis for a work classification scheme.

The 4th, 5th, and 6th digits of the occupational code numbers in the DOT reflect the relationships to

Data, People, and Things respectively, and identify the highest appropriate function in each category. The functions are ordered within each category from the most complex to the simplest, in increasing numbers. Thus function 1 is more complex than function 6 in that category (e.g., Synthesizing Data is the most complex function in that category while Comparing Data is the least).

Since, for classification purposes, it is usually sufficient to differentiate jobs on the basis of tasks, the classification scheme is based on tasks rather than on jobs. Thus, tasks (not jobs) are being classified in terms of their association with Data, People, or Things.

Ultimately, some of the information provided by the analysis is used to determine the type or degree of aggregation required, if any, in order to determine a target time for the work. In general, if the measuring level is lower than the controlling level, aggregation will be required and the target must be developed "implicitly"; otherwise, it is developed "explicitly". The difference between these approaches is explained in the next section.

The worker functions described in Figure 3 are not an exhaustive list of verbs which are used in describing tasks or elements. Therefore, Stone and Yoder (1970) constructed a standardized list of job tasks and associated them with the worker functions to describe jobs in the real work environment. This author has also developed a list of tasks and associated them with the worker function deemed most appropriate. These tasks were identified from the job descriptions of several white-collar positions. These lists are shown in Tables 6 and 7 respectively.

The verbs in both tables are followed by a code consisting of a letter indicating the major functional area as Data, People, or Things and a digit which indicates the specific level of worker function in that area.

The verbs and their associated codes in Table 6 have been accepted as valid without any further investigation. The verbs and assigned codes presented by this author were subjected to a consensus validation. That consensus was obtained by analyzing the results of a questionnaire which were sent to 17 persons.

The 17 participants consisted of 10 individuals in Personnel Classification at two different local companies (7 and 3 each), 2 students, 2 English instructors (one of

Table 6

List of Action Verbs and Their Worker Functions
As Defined by Stone and Yoder

accumulate	D3	direct	D1	measure	D3
advise	P0	discover	D0	mediate	D3
amuse	P4	discuss	P6	meet	P6
answer	P6	distinguish	D6	motivate	P5
appoint	P3	duplicate	D5	observe	D3
appraise	D2	enforce	P3	order	P3
arbitrate	P0	entertain	P4	organize	D1
arrange	D6	estimate	D4	plan	D0
assign	P3	evaluate	D2	plot	D4
assist	P7	examine	D2	post	D5
attend (to)	P7	execute	D1	prescribe	P0
audit	D2	experiment	D2	prognosticate	P0
authorize	D1	explain	P2	promote	P5
bargain	P1	forecast	D0	provide	P7
calculate	D0	formulate	D1	question	P6
calibrate	D3	grade	D6	quote	D5
choose	D6	greet	P6	rank	D6
classify	D6	humor	P4	rate	P3
coach	P2	hypothesize	D0	reason	P1
collect	D3	identify	D2	recommend	D2
compare	D6	imitate	P4	reconcile	P0
compose	D0	implement	D1	record	D5
compute	D4	index	D6	regulate	D1
confer	P1	indicate	P6	relay	P6
console	P0	influence	P5	report	D2
consult	P6	inform	P6	request	P6
contrast	D6	inspect	D6	research	D2
control	D1	instruct	P2	scan	D2
convince	P5	interest	P4	schedule	D1
counsel	P0	interpret	D0	scrutinize	D2
count	D3	interview	P6	segregate	D6
debate	P1	invent	D0	select	D6
decide	D1	inventory	D3	sell	P5
deliberate	D1	investigate	D2	settle	P1
demonstrate	P2	judge	P0	smell	D3
describe	P6	lead	P3	solicit	P5
design	D0	lecture	P2	solve	D0
determine	D1	list	D5	sort	D6
develop	D1	listen	D3	study	D2
devise	D0	manage	D1	suggest	D2
diagnose	P0	marshall	D1	summarize	D2
dictate	P6	match	D6	supervise	P3

Table 7

List of Additional Verbs and Their Worker Functions
As Defined by This Author

accompany	P7	decorate	T6	locate	D5	reproduce	D5
activate	T2	delegate	P3	mail	P6	resolve	D1
adjust	T2	delineate	D5	maintain	T2	review	D2
administer	P6	deliver	P6	manipulate	T4	rewrite	D5
aid	P5	depress	T6	mark	D6	screen	D2
align	T0	detect	D0	massage	P7	search	D6
allocate	P3	discriminate	D5	mentor	P0	serve	P7
allow	P3	disconnect	T4	mix	T7	service	T7
analyze	D1	distribute	T7	model	P6	setup	T0
appear	P7	draw	D0	monitor	T5	signal	P6
apply	D1	dress	P5	mount	T0	sketch	D0
approve	D1	drive	T3	move	T7	speak	P6
assay	D2	dump	T6	negotiate	P1	specify	D1
assemble	D6	educate	P2	notify	P6	stand	P7
assess	D1	enlist	P5	observe	P6	start	T2
attach	T6	ensure	P3	obtain	P8	stimulate	P4
attend	P7	enter	D5	offbear	T6	stop	T2
balance	D5	erect	T0	operate	T2	store	D3
build	T0	establish	D0	orient	P2	structure	D0
call	P6	explore	D1	originate	D0	survey	D2
carry	T7	fabricate	D0	oversee	P3	synchronize	T1
categorize	D5	feed	T6	pack	T7	synthesize	D0
catalog	D5	file	D6	participate	P7	tabulate	D4
cater	P7	fill	T3	perform	P4	take	P8
check	D2	fit	T1	persuade	P5	teach	P2
clean	T7	form	D0	place	T6	tend	T5
close	T2	furnish	P3	plug	T7	test	D2
code	D5	gather	D3	portray	P6	trace	D5
collate	D3	gauge	D4	position	T1	track	D5
communicate	P2	give	P7	prepare	T7	transcribe	D5
compute	D4	govern	D1	present	P6	translate	D6
compile	D3	guide	P3	press	T7	transmit	P2
conduct	D1	handle	T7	pull	T7	treat	P7
conceive	D0	help	P6	purchase	P5	turn	T3
connect	T3	immerse	T7	push	T7	type	D5
consolidate	D3	insert	T6	quote	P6	unload	T6
construct	T0	install	T0	read	P6	unlock	T0
contract	P1	intercede	P1	receive	P8	use	T7
control	P3	interpolate	D3	refer	P0	verify	D6
correct	D2	issue	P5	regulate	T2	visit	P7
correspond	P6	itemize	D3	rehearse	P6	walk	P7
cooperate	P4	join	T4	relay	P6	wash	T7
coordinate	D1	keep	P7	remove	T6	weigh	D3
copy	D5	lift	T7	render	P7	wrap	T7
create	D0	load	T6	represent	P1	write	D5

whom is a lawyer and linguist), and 3 other individuals in various professional positions. Of that 17, 11 were returned, representing a response rate of 64.71%. However, the analysis was based on 58.82% of the sample because one of the responses was not used because of possible acquiescence. The values given in Table 7 are the adjusted sample means (the Mean minus the Standard Error of the Mean).

As stated earlier, the DOT uses worker functions to describe and classify jobs. An analysis of several jobs in the Professional/Technical occupational category was performed to develop a worker function profile for white collar workers. The purpose of this effort is to define knowledge workers and to identify the tasks involved in their work. A summary of this analysis is presented in Table 8.

The percentages shown in Table 8 indicate the percentage of all jobs in each occupational field having the given worker function level. The levels shown are the worker functions performed by at least seventy-five percent of all job listings for each worker field.

The primary worker functions for all occupations listed in the DOT, were determined, and a list of the most probable worker functions was derived from their

Table 8

Analysis of Jobs by Worker Functions
As Described by the DOT

WORKER FIELD	DATA	PEOPLE	THINGS
Sales	3 Compiling 69.7% 4 Sales 13.5	5 Persuading 79.3%	7 Handling 90.0%
Managers	1 Coordinating 97.6	6 Speaking 68.6 1 Negotiating 28.4	7 Handling 97.9
Administrative	1 Coordinating 57.1 2 Analyzing 33.9	6 Speaking 70.8 1 Negotiating 11.9	7 Handling 95.8
Clerical	3 Compiling 51.9 1 Coordinating 15.6 5 Copying 14.8	6 Speaking 43.0 8 Taking Instr. 42.6	7 Handling 59.5 2 Operating 35.2
Engineers	1 Coordinating 40.2 0 Synthesizing 31.7	6 Speaking 80.3	1 Precision Working 67.9 7 Handling 28.9
Medical	1 Coordinating 56.6 3 Compiling 25.0	6 Speaking 34.2 0 Mentoring 27.0 2 Instructing 16.4	1 Precision Working 55.3 7 Handling 25.0
Scientists	0 Synthesizing 56.9 1 Coordinating 21.2	6 Speaking 78.1	1 Precision Working 55.0 7 Handling 37.7

combinations. That list and its intuitive grouping are shown in Figure 4.

An intuitive clustering to determine classes of workers based on the above worker functions is shown in Table 9. It is based on the Data (D), People (P), and Things (T) construct as used in the DOT. However, the worker functions were initially intended to describe tasks, and the DOT process of assigning them to jobs is not known.

041 047	101		301	
	107		307	
	117	217		
	121		321	
	127	227	327	
	131		331	631
	134		334	634
	137		337	637
	241		341	
	247		347	
			357	457
061	161	261	361	661
	162		362	562 662
	163		363	663
	164		364	664
	165		365	665
067	167	267	367	567 667
	174		374	674
	177		377	677
081	181	281	381	681
	182		382	582 682
	183		383	683
	184		384	684
087	185		385	685
	187	287	387	587 687

Figure 4. Primary DOT Worker Functions

Table 9

Intuitive Job Clusters From DOT-Assigned Worker Functions

CONDITION	CLUSTER (MEMBER)
D = 0	Creative Worker (Scientist)
0 < D <= 2 AND P <= 2	People Professional (Doctor)
D = 3 AND 0 <= P <= 2	Assistants to People Professionals (Nurse's Aide)
P = 3	Supervisor
D = 3 AND P >= 6	Clerical Worker (Secretary/Clerk)
5 <= D <= 6 AND P >= 6	Manual Worker (Machinist/Operator)
P = 5	Salesperson (Real Estate Agent)
D = 1 AND P >= 6	Technical Professional (Engineer)
D = 2 AND P >= 6	Asst. to Technical Professional (Drafter/Tester/Technician)
D = 4 AND P >= 6	Service Worker (Waiter)

Illustration of the Classification

The job of Systems Analyst was analyzed by using a slightly modified version of the Sentence Analysis Technique (SAT) described in the Handbook for Describing Jobs. This modified SAT has a column for the worker function, in addition to the customary columns for the verb, its object, and the infinitive. The worker

functions are based on the codes listed in Tables 6 and 7. This analysis identifies the work which is performed, its object, and the purpose. Figure 5 illustrates this analysis.

POSITION: Supervisor, Systems Analyst

VERB	OBJECT	INFINITIVE AND ITS OBJECT	WORKER FUNCTION
Consults with	potential users	to document information requirements	P6
Analyzes	existing systems		D2
Works with	project team	to formulate systems specifications and approaches	P7
Prepares	economic evaluations		D3
Delineates	system components		D6
Prepares	system flowcharts		D3
Structures	system logic		D0
Develops	forms		D1
Designs	output		D0
Formulates	procedures		D1
Writes	manuals		D5
Prepares	training materials		D3
Evaluates	performance		D2

Figure 5. Sample Job Analysis

Task Classifications

Since white-collar work is not readily decomposable to units smaller than tasks, the initial classification of white-collar work will begin at the task level. Using the construct of Data-People-Things, the following task classifications are being offered in Figure 6.

A Task is assigned to one of these classes depending on whether it is primarily involved with Data, People, or Things and the index within that involvement category. Several tasks are often scheduled, assigned, and performed in order to accomplish a given end. The manner in which these subtasks are grouped into larger task units may differ from organization to organization, but the need to manage these units is the same. Hence, as the subtasks are aggregated into manageable-sized task units, an aggregation can also be performed on the

<u>DATA</u>	<u>PEOPLE</u>	<u>THINGS</u>
0 Creating Information	0-3 Leading People	0-1 Applying Perception in Working with Things
1-2 Processing Information	4-5 Persuading People	2-4 Applying Discernment in Working with Things
3-6 Gathering or Disseminating Information	6-8 Serving People	5-7 Applying No Judgment in Working with Things

Figure 6. Task Classifications

associated worker function. Jobs are classified according to the results of all tasks comprising them.

The results from the performance of the tasks will either be tangible (products), intangible (services), or not actual (nothing). These results can usually be determined from the classification of the task. The expected results from the tasks, as classified in Figure 6, are shown in Figure 7.

Figure 7 provides guidelines for associating task results with task classes. Jobs, on the other hand, can be classified as performing skill-based work, knowledge work, or work by presence; and the results associated with each are usually tangible, intangible, and non-existent, respectively. (The third class represents those workers whose purpose is primarily to be on the job.)

<u>DPT - TASK</u> <u>CATEGORY</u>	<u>INDEX</u>	<u>TASK</u> <u>CLASSIFICATION</u>	<u>EXPECTED</u> <u>RESULT</u>
DATA	0	CREATING INFORMATION	INTANGIBLE
DATA	1-2	PROCESSING INFORMATION	INTANGIBLE
DATA	3-6	GATHERING INFORMATION	TANGIBLE
PEOPLE	0-3	LEADING PEOPLE	INTANGIBLE
PEOPLE	4-5	PERSUADING PEOPLE	INTANGIBLE
PEOPLE	5-8	SERVING PEOPLE	INTANGIBLE
THINGS	0-1	PERCEPTION REQUIRED	TANGIBLE
THINGS	2-4	DISCERNMENT REQUIRED	TANGIBLE
THINGS	5-7	NO JUDGMENT REQUIRED	TANGIBLE

Figure 7. Results per Task Class

These job classifications are not restricted to any particular work environment, but may be found in the office or on the plant floor.

Summary

The work classification approach facilitates the identification of an "action verb" of the work performed and, together with the Data-People-Things construct, the "object" upon which it was performed. The "action verb" identifies what is to be done, and the "object" identifies what is to be counted. Ideally, the classification approach should be applied to all levels of the heirarchial structure, thus permitting aggregation of all work results upward. Application of the heirarchial structuring and classification identifies all levels of work units and work-unit counts by identifying the constituent work-units and facilitating the identification of their "outputs". They help in identifying the measuring, the controlling, and managing work levels and shows the relationships among them. The work analysis also serves as the basis for determining the most appropriate tool to measure the work accomplished and to determine the necessary labor input to achieve a desired productivity level given the expected output.

At the end of the analysis, such information is known as the levels of work for measuring, controlling, and managing; the object or result of the work; and the classification of the task or element being measured. This information, particularly that associated with the task classification, is necessary for the next step in the methodology - the measurement.

Work Measurement

Introduction

Work measurement is the systematic determination, through the use of various techniques, of the amount of effective work (both mental and physical) in a specific task (Whitmore 1971). Its primary objective is the derivation of time standards or targets to act as criteria against which employee performance may be measured. (The term "standard" is used only with regard to work which is highly repetitive in nature from job to job; otherwise, the term "target" is used.) These targets are the expected times for an "average" employee to complete a task at a "normal" pace.

Once the target has been established it may be used for such purposes as

- (1) Determining "production" costs,
- (2) Determining staffing requirements,

- (3) Determining correct workloading,
- (4) Providing the basis for labor control, or
- (5) Providing the basis for incentive schemes.

The intended use of the target may affect the choice of technique by which it will be determined, recognizing that some techniques may provide a greater degree of accuracy than others and thus require more time, increasing the corresponding cost.

The problems encountered in measuring knowledge work are due, to a great extent, to its nature. Knowledge work consists of tasks and task elements which are not highly repetitive, and it rarely yields a quantifiable or definable output; it is often accomplished as a group effort; and there are usually several routes by which it may be executed. This high degree of variability found in performing knowledge work defies the traditional approach of first standardizing the method by which the work is performed, before measuring it. However, this approach is paramount to the successful application of many of the traditional measurement techniques. Thus, the nature of knowledge work prevents its measurement by many of the traditional techniques.

In essence, all work is the same in that work of any nature requires the expenditure of human energy - whether static or dynamic. Although techniques for measuring

knowledge work have been slow in development, the control sought through measurement can be obtained through adjustments in the application of some of the techniques proven in the direct-labor area (those techniques which allow for the nature of knowledge work.) The adjustments to these techniques might occur in the initial assumptions, the actual execution, or in the interpretation and usages of the results.

Thus, it is possible to "measure" any kind of work; however, it may not be feasible to develop universal standards for all types of work and their constituent tasks.

Consider the previous example of the task "Design Computer System." Although numerous computer systems have been designed, if the range of task completion times run from several hours for one individual to years for a team, the "expected task completion time" of, say, 543 man-hours would be of little value. Thus, it is especially doubtful that standards for knowledge work could be developed for universal application. However, individual firms could develop their own set of operational standards if the appropriate tools were chosen. The next section presents a tool for selecting a measurement technique. This tool addresses the problem

of pairing the work-unit and the measurement technique based on their respective natures and characteristics.

Choice of Measurement Technique

Most jobs require the performance of a variety of tasks, skill-based and knowledge-based. The relative amounts of each, however, determine the overall nature of the job and the level at which control is exercised. Knowledge-based tasks are usually performed as part of an individual job assignment or a group assignment, while skill-based tasks are usually performed as a result of a direct assignment. Hence, if measurement is to take place one level lower than the control level, knowledge-based tasks should be measured at the task level and skill-based tasks at the behavior level. In fact, this is the level measured in most systems which provide predetermined times for elemental physical motions.

The choice of the most appropriate tool or tools for collecting and analyzing work measurement data depends on several variables. These include the variety of tasks, the frequency of each task, their cycle regularity, the complexity of the tasks, and the variability in the methods by which each task may be accomplished. The first three variables describe the collection of all

tasks in a job, while the remaining refer to the individual tasks.

Two of the job-related parameters are the frequency of each task and the regularity with which each occurs. Task frequency is the number of occurrences per measuring period, and the cycle regularity indicates whether the task occurs on a regular schedule, an irregular schedule, or no schedule at all.

The parameters which describe the individual tasks are the complexity and the variability. Complexity refers to the level of knowledge or skill required to effectively perform the task, the amount of thinking time required, and the extent to which there is a known procedure that specifies the sequence of steps to be followed (Van de Ven and Delbecq, 1974; Perrow, 1967). Variability refers to the degree of stability and uniformity of the task inputs and outputs (Woodward, 1965).

Although these task parameters are independent, they will interact. As tasks become less complex through advancement on the learning curve, they may become less variable as structured procedures become more apparent. Also, as organizational procedures become more standardized tasks become less variable and thus require less thought in performing them, which will reduce the

level of complexity and the level of knowledge required to perform them.

These parameters will be used to describe jobs and their tasks and as criteria for selecting a measuring technique. The specific categories for each follows:

FREQUENCY: **ONCE**, Special or one-time;

LOW, at most twice;

MEDIUM, at most 4 times;

HIGH, At most 8 times; and

VERY HIGH, more than 8 times.

CYCLE: **REGULAR**, equally spaced intervals;

IRREGULAR, unequally spaced intervals; and

SPORADIC, no apparent interval.

COMPLEXITY: **SIMPLE**, Minimal requirements;

COMPLEX, Procedural, some thought; and

HIGHLY COMPLEX, Much decision making.

VARIABILITY: **CONSTANT**, Always done the same way;

VARIABLE, May be done differently as
dictated by conditions;

HIGHLY VARIABLE, Always different
because conditions change; and

UNCERTAIN, Conditions usually unknown.

The complexity and variability levels for each of the task classifications presented in the previous chapter are described in Table 10.

Table 10

Work Parameters of Task Classes

VARIABILITY	COMPLEXITY		
	SIMPLE	COMPLEX	HIGHLY COMPLEX
CONSTANT	P6-P8 T5-T7	D3-D6	*
VARIABLE	*	T2-T4	D1-D2
HIGHLY VARIABLE	*	D1-D2 T2-T4 P4-P5	T0-T1
UNCERTAIN	*	P0-P3	D0

KEY:

* This combination rarely occurs
 D0 Creating Information P0-P3 Leading People
 D1-D2 Processing Information P4-P5 Persuading People
 D3-D6 Gathering Information P6-P8 Serving People
 T0-T1 Physical, with T5-T7 Physical, with No
 Perception Judgment
 T2-T4 Physical, with
 Discernment

It should be noted that the higher the level of complexity, the greater the expertise required for problem solving and decision making (Perrow, 1967). Thus, it is expected that tasks in the lower indices of the worker functions have a greater degree of difficulty, require more thought in their execution, and require highly educated personnel.

Tasks with low variability generally are performed in environments with systematized programs that specify in detail the means and ends for task performance to attain high-volume, continuous, or large-batch output (Van de Ven, 1974). These programs have high degrees of pacing rules; highly detailed work steps to provide products or services according to specifications; and many built-in quality-monitoring devices (Van de Ven, 1974).

Those tasks with intermediate variability have specified outputs and a repertoire of means by which a task may be performed, allowing the individual to analyze the task and choose the appropriate procedure for performing the task (Perrow, 1970). Tasks with high variability are usually those never before performed, thus only general expectations can be specified while the means for attaining them are unspecified (Van de Ven and Delbecq, 1974).

The choice of measurement technique, based on the values of these task parameters, along with the job parameters, is shown in the decision table presented in Figure 8. From the data presented in Table 10, it appears that knowledge workers rarely perform work which is simple or constant in nature. Also, as stated earlier in the literature review, knowledge work tends to be

CONDITIONS	RULES									
	1	2	3	4	5	6	7	8	9	10
FREQUENCY - ONCE	Y					Y	Y	Y	Y	Y
FREQUENCY - LOW		Y	Y				Y			
FREQUENCY - MEDIUM										
FREQUENCY - HIGH				Y						
FREQUENCY - VERY HIGH					Y					
CYCLE - IRREGULAR	Y	Y								
CYCLE - REGULAR			Y	Y	Y	Y		Y	Y	
CYCLE - SPORADIC										Y
COMPLEXITY - SIMPLE				Y	Y	Y			Y	
COMPLEXITY - COMPLEX		Y	Y				Y	Y		Y
COMPLEXITY - HIGHLY	Y									
VARIABILITY - CONSTANT				Y	Y	Y	Y	Y	Y	
VARIABILITY - VARIABLE			Y							
VARIABILITY - HIGHLY	Y	Y								
VARIABILITY - UNCERTAIN										Y
ACTIONS										
WORK SAMPLING										1
TIME STUDY				1				1		
PMTS					1		1			
STANDARD DATA										
ESTIMATE	1					1				1
HISTORICAL DATA		1								
AVERAGE			1							
SELF-LOGGING										

Figure 8. Decision Table for Choice of Work Measurement Technique

CONDITIONS	RULES									
	11	12	13	14	15	16	17	18	19	20
FREQUENCY - ONCE	Y									
FREQUENCY - LOW		Y	Y	Y	Y	Y	Y			Y
FREQUENCY - MEDIUM								Y		
FREQUENCY - HIGH										
FREQUENCY - VERY HIGH									Y	
CYCLE - IRREGULAR										Y
CYCLE - REGULAR	Y	Y	Y	Y	Y	Y		Y		
CYCLE - SPORADIC							Y		Y	
COMPLEXITY - SIMPLE										
COMPLEXITY - COMPLEX	Y	Y	Y	Y	Y	Y	Y	Y		
COMPLEXITY - HIGHLY									Y	Y
VARIABILITY - CONSTANT		Y		Y	Y	Y				
VARIABILITY - VARIABLE	Y		Y					Y		
VARIABILITY - HIGHLY							Y			Y
VARIABILITY - UNCERTAIN									Y	
ACTIONS										
WORK SAMPLING						1				
TIME STUDY				1	1					
PMTS		1								
STANDARD DATA								1		
ESTIMATE			1							
HISTORICAL DATA							1			1
AVERAGE										
SELF-LOGGING	1								1	

Figure 8 (Continued)

nonrepetitive (infrequent) and noncyclical. Thus, the characteristics of knowledge work indicate that it is best measured by Estimating, Historical Data, Averaging, or Self-logging. (See Rules 11, 13, 17, 19, and 20).

For any rule in which the indicated conditions hold true, the recommended action is to choose the indicated measurement technique (e.g., Rule 1: If frequency = once, cycle = irregular, complexity = highly complex, and variability = highly variable; then the recommended action is to use Estimating as the measurement technique.)

The techniques in Figure 8 tend to be more effective for measuring certain types of work. Those techniques, the types of work for which they are best suited, and a description of their application are provided in Table 11.

Summary

This step of the methodology results in the identification of a measurement technique based on the characteristics of the work-unit. The time obtained from the measurement, however, cannot be used as a legitimate target time until it represents a "normal" time for the "average" worker to complete given the particular characteristics of the task at hand. Specifically, something must be done to reduce the variation in knowledge related tasks. Analogously in manual work measurement, this is accomplished through pacing, an

Table 11

Work Measurement Techniques and Their Application

Technique	Type of Work	Application
WORK SAMPLING	Irregular work where the output is highly correlated to the work input.	1. Define basic work units. 2. Establish number of observations for statistical reliability. 3. Set up schedule for random observations. 4. At scheduled time, make observations and tally. 5. Obtain production count during study. 6. Rate performance. 7. Determine and apply allowances.
TIME STUDY	Repetitive, short cycle work performed at one work station; or Irregular, medium to long cycle work, frequently performed by moving about several work stations.	1. Conduct detailed methods study. 2. Establish work units to be timed. 3. Record time with a stopwatch. 4. Establish statistical reliability. 5. Rate performance. 6. Determine and apply allowances.
PMTS (Predetermined Motion-Time System)	Repetitive, short cycle physical work where volume is high.	1. Break down work into basic motions. 2. Make measurement of all variables. 3. Determine time values from tables. 4. Determine and apply allowances.
AVERAGE	Complex work which reoccurs infrequently	1. Sum the actual work-unit times. 2. Divide the sum by the number of work units.

Table 11 (Continued)

Technique	Type of Work	Application
STANDARD DATA	Repetitive, medium cycle work where volume is high; or Repetitive work where volume is low; or long irregular cycle work where volume is high.	1. Determine and define basic motions. 2. Average the variables into categories. 3. Determine time values from PMTS tables. 4. Arrange data into tables.
ESTIMATE	Highly technical or irregular work.	1. Breakdown work into smallest work units. 2. Estimate time it should take to perform work. 3. Record data and evaluate. 4. Determine and apply allowances.
HISTORICAL DATA	Irregular work where a work unit may be determined.	1. Analyze records of hours expended and related output units produced. 2. Measure central tendency. 3. Select realistic work unit and correlate input to output.
SELF-LOGGING	Irregular work in which each person decides how it is to be performed.	1. Define basic work unit. 2. Establish number of observations for statistical reliability. 3. At scheduled time, record the time for work unit performed. 4. Tally time for each work unit. 5. Determine and apply allowances.

adjustment to "standardize" the time due to the work pace of the individual upon whom the measurement was made.

With knowledge work, a special kind of "pacing" is required. This pacing improves the estimate of the target time by reducing the inherent variation in knowledge work task completion times. It recognizes the differences from job to job or task to task, differences which reflect the peculiarities of the work and account for most of the variance observed in knowledge work. By folding in the recognized differences, variation in the target time for the next similar task can be reduced. The development of this step of the methodology is explained in the following section.

The Target Time

Introduction

The variation in time required to complete a task is a function of two types of variables - those that affect the task as a whole and those related to or contained in the lower elements of the task. The values of these variables cause the variation in the completion times of similar tasks in knowledge work.

To illustrate the first variable type, consider the previous task example, "design computer system" and the previously identified parameter "complexity". If the

target time for this task is X hours, and if the next similar task is twice as complex as the average task, then the target time for the next similar task might be two times X. This approach improves the target time by operating explicitly on the expected time.

To illustrate the second variable type, consider the same example, but suppose this task is composed of elements such "write computer programs". If the average task requires X computer programs, and if the next similar task requires two times X computer programs, then the target time for the next similar task might be 1.3 times X longer. In any case, the target time for the next similar task would be nearer the actual completion time than the old average time, (i.e., the target time would be improved). This approach improves the target time by operating implicitly on the expected time.

Determining the Level of Measurement

The heirarchial structuring and task classification break work into succeeding lower levels and provide an approach for what to measure and what to count. Yet to be determined is the appropriate level to perform the measurement. Referring to Table 5, one recalls that at level one, mental behaviors are often not discernible nor measureable, and that level three, tasks may be of long

or short duration (recall the task example of "design computer system".) Since the heirarchial structuring breaks all work into "action verb" and "object" components, the level at which the measurement is made is arbitrary from that perspective. Thus, Table 12 reflects the usual duration time for the various levels of work. Note that task completion times usually vary from man-hours to man-months. Since the measurement should take place at the task level, this implies that the target time would be in man-hours to man-months. If the user of the methodology concurs with target times within this range, the structuring has been completed to the appropriate level. If not, further (less) breakdown is necessary until the target time is within the range desired by the user.

The Explicitly Improved Target Time

In knowledge work, tasks might not be readily decomposable so that times could be developed for each of its elements. In such a case, the time target must be developed by enhancing the result of the measurement "explicitly". This implies that the reporting level is also the measurement level. Thus, instead of building improvements into the development of the standard, the overall time obtained from the measurement is improved to

Table 12

Levels of Accountability and Reporting Time-Frame

OUTPUT NAME	TIME REFERENCE FOR MEASUREMENT AND CONTROL						
	MIN.	HRS.	DAYS	WKS.	MNTH.	ANN.	YRS.
Global End							*
Intermediate Goal						*	*
Program					*	*	*
Mission					*	*	
Job					*	*	
Task		*	*	*			
Element		*	*				
Behavior	*	*					

become the target time of the work-unit. Thus, the parameters of interest are those which affect the total action itself, the verb-parameters. Some questions which might provide information concerning action characteristics that affect the completion time are how often, for what reason, in what manner, and with what difficulties or restrictions affect the completion time. Table 13 reflects possible parameters based on the Data-People-Things construct. Parameter identification and application is explained in detail later in this chapter.

Table 13

Object Types and Parameters

OBJECT-TYPE	OBJECT-PARAMETERS
DATA	AMOUNT, COMPLEXITY, PRESENTATION
PEOPLE	NUMBER, POSITION, FUNCTION
THINGS	NUMBER, SIZE, FORM, FUNCTION

The object here is to improve the target time for a task which has characteristics (parameters) that affect, inherently and as a whole, its completion time. The target time improvement can be described in a mathematical model as follows:

Target Time = $K_0 + (\text{Expected time}) * \sum[(V_i W_i)/P_i]$,
 where Expected time is derived by any method previously described or from completion of a similar task,
 P_i is the i th parameter value affecting task completion time in arriving at the expected time,
 V_i is the value for the parameter i for the target time prediction,
 W_i is a weight to be assigned to parameter i ,
 and K_0 is a constant.

The values for P_i and V_i are dependent on the characteristics of the tasks and may be determined by a number of procedures. They may be estimated by an analyst or through a consensus resulting from input from

several parties involved in the work, perhaps through the Nominal Group Technique. The constant times (K_0) are the times required to perform tasks or elements which are consistent regardless of differing characteristics (such as set-up or start-up times).

The concept presented in this methodology is analogous to pacing, which is done to assess the worker's rate of working with respect to the "standard rate", and to make necessary adjustments in the time to compensate for this rate. The adjustment in this model is based on a comparison of the values of the time-affecting factors against the "standard values" which were present at the time of the measurement.

The Implicitly Improved Target Time

Suppose the task can be broken down into sub-tasks or elements some of which can be measured and associated with a work-unit count and some of which are affected by characteristics (parameters) as in the explicit case. The approach for this situation involves an "implicit" improvement in the development of the target time for the total work-unit by accounting for elements associated with work-unit counts as well as all parameters which might affect the completion time of the lower level elements. Again, the aggregation levels should be based

on the guidelines in Table 11 for determining the level of work at which reporting is required.

The object now is to develop a target time implicitly by using elements of the task and parameters affecting the task. This model can be expressed mathematically as follows:

Target Time = $K_0 + \sum[C_i * K_i] + \sum[P_j * K_j]$, where
 K_0 is a constant as in the explicit case,
 C_i is the i th work-unit count,
 K_i is the time associated with the i th work-unit count,
 P_j is the j th parameter affecting task completion,
 K_j is the multiplier of the j th parameter as in the explicit case.

Application of this model requires that tasks or elements be identified to determine their constant contents, their variable contents, and the parameters which affect that variability. Such information greatly depends on whether the object of the task is Data, People, or Things. These object-parameters need to be taken into account when the time standard for the task or element is being developed as components of an overall time standard. Some possible object-parameters for each object type are listed in Table 13. This list is not all inclusive, but it offers a guideline by which others might be identified.

Table 13 indicates that for all object types the primary question which might be asked in identifying

object parameters is how many or how much; and for each counted, the questions might include what type is it, how is it structured, and what does it do.

Parameter Identification

The desired values of the target time for each work unit should depend only on the characteristics of the units themselves, with respect to the "average" worker, and should not be affected by variations from worker to worker or from state to state. Those characteristics of the work or its object which affect the completion time and cause much of its variation are called "parameters". The identification of those parameters is essential in explaining the variance from task to task among similar tasks and in developing a time or at least a model which accounts for the parameters.

The concept of verb and object parameters was introduced in the previous section. The verb parameters reflect the characteristics of the work itself, and the object parameters reflect the characteristics of the object of the verb, based on whether it is Data, People, or Things. An example of an analysis to determine both the object and verb parameters which might affect the time to complete a given work-unit is shown in Figure 9. The verbs and objects listed are the tasks listed in the

POSITION: Systems Analyst

VERB	OBJECT	VERB PARAMETERS	OBJECT PARAMETERS	CODE
Consults with	potential users	FREQUENCY PURPOSE MANNER LOCATION AVAILABILITY	NUMBER KNOWLEDGE	P6
Analyzes	existing systems	DETAIL QUALITY KNOWLEDGE	SIZE COMPLEXITY	D2
Works with	project team	FREQUENCY PURPOSE MANNER LOCATION	NUMBER POSITIONS FUNCTIONS COOPERATION	P7
Prepares	economic evaluations	DETAIL QUALITY	NUMBER COMPLEXITY	D3
Delineates	system components	DETAIL LOCATION	NUMBER COMPLEXITY	D6
Prepares	system flowcharts	DETAIL	COMPLEXITY TYPE	D3
Structures	system logic	DETAIL	COMPLEXITY	D0
Develops	forms	DETAIL	COMPLEXITY NUMBER TYPE CONTROLS	D1
Designs	output	DETAIL AUDIENCE	COMPLEXITY NUMBER	D0
Formulates	procedures	DETAIL	COMPLEXITY NUMBER PURPOSE	D1

Figure 9. Parameter Identification

job description of the systems analyst job. If the task listed represents the lowest level of work to be accomplished, the verb-parameters should be applied in developing the target; if, however, the task consists of smaller elements, then the task target is an aggregate of the element times which are affected by the object-parameters.

Determination of the K-Multiplier Values

Clearly, the measurement of knowledge work will involve intangibles. Further, a major effort has been expended in identifying quantifiable intangible parameters that can improve measured times into target times. What yet remains is a methodology to determine the K-multiplier values. In any case, these values can be estimated by an objective and experienced analyst (for shorter tasks) and by consensus groups (for longer tasks). This approach appears to be the best approach for the "explicitly" improved target time and the only approach where similar tasks have never been performed or very few times (say, less than five times). It seems intuitive that an improvement will occur; however, the degree of improvement will depend on the ability of the analyst/consensus-group. Perhaps over time, a collective body of experience and knowledge will result in excellent

target times; however, there remains no way to demonstrate in advance that such improvement will occur.

For the "implicitly" improved target time for tasks that have a greater occurrence of similar tasks, an attractive alternative exists. The K values in the mathematical model can be derived by regression analysis. Also, if a "true" target time exists, as the number of data points (completion of similar tasks) increases, the predicted target time determined by the regression model converges to the true target time (see Figure 10).

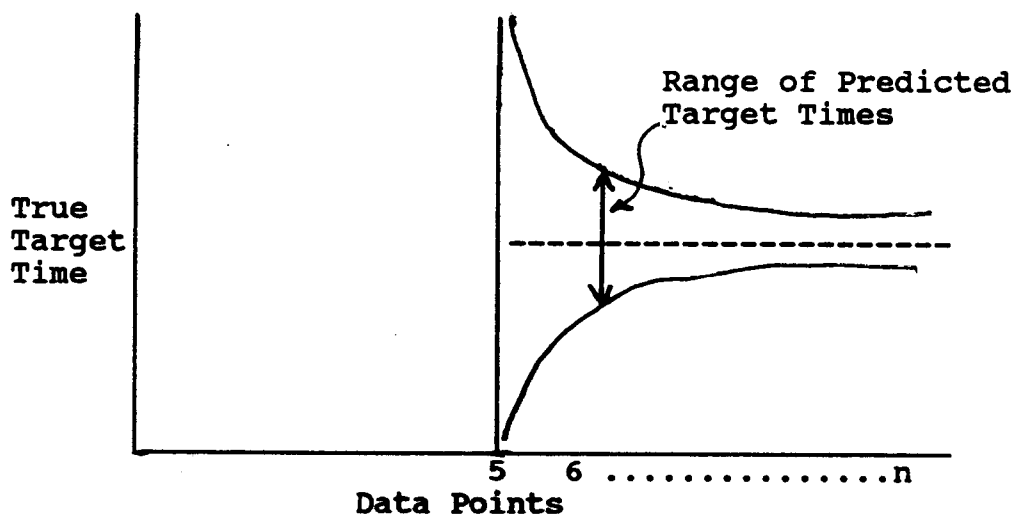


Figure 10. Target Time Convergence

Regression Concerns

The objective of regression analysis is to develop an equation to predict the value of some dependent

variable based on the values of one or more independent variables. For the "implicit" model, that dependent variable is the target time of completion for a task, and the independent variables represent the variable contents of the elements and the parameters which affect that variability. However, the inclusion of a large number of independent variables in a regression model often results in multicollinearity.

Multicollinearity is defined as a high degree of multiple correlation among several independent variables. It often results in coefficient estimates that have incorrect signs or magnitude. Thus, only those factors which are necessary to produce the variance in the target time should be considered. This is made possible by preceding the development of the model with an interpretive technique such as Factor Analysis (FA) or Principal Components Analysis (PAC). These techniques are designed to identify intercorrelated variables and characteristics of the system which are statistically independent, but nonmeasurable. The technique chosen for this research is Factor Analysis.

FA is dependent upon linear relationships among the variables. If linear relationships do not exist, the data must be reduced to linear relationships by using an appropriate transformation in order to analyze them.

Thus, in order to apply factor analysis to the data, their linearity must be determined, and the results of the factor analysis can then be used in a regression analysis to determine the coefficients of the factors which indicate the target completion time.

A covariance analysis performed on the data will assist in determining the linear association of the variables. If both fall on the same side of their means, the covariance is positive; otherwise, it is negative. If there is no apparent linear association, the covariance will be near zero.

An unsatisfactory feature of the covariance as a measure of linear association is that it is scale dependent. This is corrected by standardizing x_1 and x_2 , which converts the covariance to the correlation. Thus the correlation always lies between +1 and -1: a value of +1 implies a perfect positive linear association, a value of -1 implies a perfect negative association, and a value of zero implies no association.

It is important that intercorrelations be identified because they may lead to irrational regression coefficients, which in turn, may lead to irrational predictions. The coefficients may be statistically sound and still be irrational in magnitude or in sign.

The FA identifies the subset of variables which might be included in the model. These variables are selected according to Kaiser's Rule of Thumb (McCuen 1985) which identifies significant variables as those with an eigenvalue greater than 0.80. It also provides information for selecting the model variables from the identified subset. These are the variables with the highest loading in each of the eigenvectors of the significant eigenvalues previously identified. Also, the intercorrelation among these variables must be determined before the final selection can be made. The selected variables may then be used to develop the regression model.

An alternative to preceding the model development with an FA is to develop the model using Stepwise regression. The Stepwise development usually avoids irrational coefficients because the statistical criteria that are used in selecting the independent variables tend to eliminate those variables which have high intercorrelations.

Regardless of the approach used to develop the model, it should be evaluated to determine how well it

represents the observed data. Criteria for this evaluation are

1. Rationality of the coefficients,
2. Coefficient of Multiple Determination, R^2 , and
3. The relative importance of the independent variables.

The rationality of the coefficients is answered by determining if the values are logically consistent, in terms of magnitude and sign, with the relationships represented by the model; R^2 represents the percentage of the dependent variable which is explained by the independent variables in the model; and the relative importance or significance of the independent variables is determined by the partial F test. For each independent variable, this procedure tests the acceptance of the null hypothesis that the coefficient value is zero or insignificant. The hypothesis is rejected if the test statistic exceeds the critical F value at a level of significance 0.05 with $(1, N - k - 1)$ degrees of freedom, where N is the number of observations and k is the number of variables.

With the analysis complete, predictions can be based on the developed model with a greater degree of confidence, and as the number of observations increases,

so will the accuracy of the predictions based on the constantly improving model.

SUMMARY

Figure 11 contains a diagram of the methodology presented in this chapter. This methodology provides guidelines for (a) structured analysis of the work to be performed; (b) selection of the most appropriate technique to measure the work, given its characteristics; (c) determination of the parameters (both verb and object) which affect the time to complete the work; and (d) calculation of the target time which accounts for factors previously omitted in traditional methods for determining standard times.

As a result of this methodology, we can generalize about the standard or target time per unit of output for any work unit if the output is defined, and if all of its constituent work units are known, along with their completion times. For knowledge work, if the measurement is required at any level higher than the task level, the measurement will be an aggregation from the task level on up to the level in question. This aggregation is facilitated if the tasks are contiguous; if they are not, time must be allowed for the interruptions or delays which occur. Also, if any of the tasks are performed

simultaneously, as is often the case with knowledge work, the standard time is based on the combined time.

Applications of the methodology prescribed are presented in chapter 4.

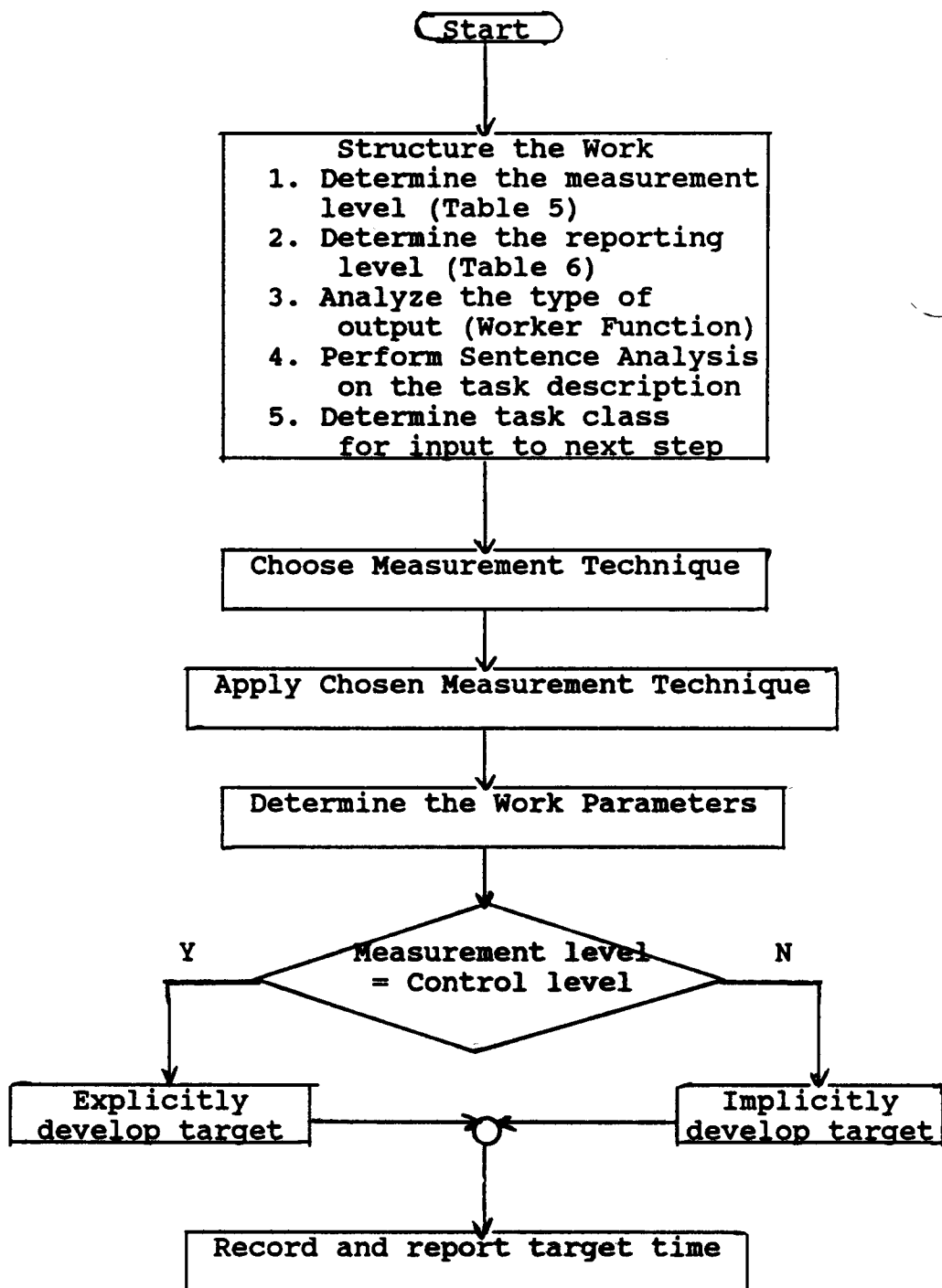


Figure 11. Work Measurement Methodology

CHAPTER IV

APPLICATION OF THE MEASUREMENT METHODOLOGY

Introduction

The methodology for analyzing and measuring knowledge work to develop a target completion time will now be applied to two sets of organizational data. A summary of the steps involved are

1. Analyze the work by
 - a. determining the measurement level,
 - b. determining the reporting level,
 - c. determining the type of output, and
 - d. determining the task class;
2. Select the measurement technique;
3. Apply the chosen measurement technique;
4. Determine the work parameters; and
5. Develop the target time either implicitly or explicitly, as dictated by the relationship between the measuring and reporting levels; and perform the necessary analyses.

These steps are applied to data from two local companies, Company A and Company B, which have asked to remain anonymous and which are involved in knowledge work. These data provided descriptions of the tasks, their elements, and the factors which affect the completion

time, as well as the task completion times. The applications of the data from Company A and Company B follow in the next two sections.

Company A Application

Step One: Heirarchial Structuring of the Work

Company A performs work under government contracts. This work is performed at one of the three sites or as joint site projects. The data presented represents the planning phase of projects conducted at one of the plant sites.

First, the work structure was identified to determine the level at which the work should be measured. It is presented in Figure 12, which indicates that the work can be effectively decomposed to a smaller work-unit than the task, namely, its elements.

The next operation in the work structuring is to determine the reporting level. The hours are reported weekly with Engineering Service Orders (ESO's) reflecting the phase of Project Planning on which work is being performed (the task level), and Table 12 indicates that weekly reporting is either at the task or job level. For this company, the reporting level is the task.

8th Order Work Unit (Global End):	Company Strategic Goals
7th Order Work Unit (Intermediate Goal):	Installation Goals
6th Order Work Unit (Program):	Installation Projects
5th Order Work Unit (Mission):	Installation Operations Projects
4th Order Work Unit (Job):	Project Planning
3rd Order Work Unit (Task):	Feasibility Study
2nd Order Work Unit (Element):	Economic Analysis Technical Analysis Operational Analysis
1st Order Work Unit (Behavior):	Can Not Be Determined

Figure 12. Company A: Work Structure

At this stage, the measurement and the reporting levels are known. This information will be used later to determine how the target time should be calculated.

The data collected by and received from the Engineering Information Systems organization were the hours expended to perform task, the feasibility study, and a description of the task. It does not indicate at which level measurement is currently taking place, only that reporting is taking place at the task level. This description indicated the elements of the task and their characteristics. These elements are the specific

analyses which are conducted when a feasibility study is performed.

Project planning, applied to 24 Operations projects at the installation in question, consists of 4 phases: feasibility study, development of the conceptual design, determination of the design criteria, and the planning and scheduling of construction. Hours were collected for the feasibility study, which has three elements: Technical Analysis, Operational Analysis, and Economic Analysis.

The technical analysis consists of literature reviews and interviews of experts to determine if the design can be developed and implemented using existing technology: the operational analysis consists primarily of interviews to determine the environment (personnel and procedures) in which the completed project will operate; and the economic analysis primarily is a cost/effectiveness analysis to determine if the benefits of the project are worth the resources required to implement it.

These elements and their parameters (those characteristics of the work which affect the completion time of the work-unit), as well as their values, were determined from interviews. They will be used as variables in the model to determine the target completion

time. The three types of analyses which comprise the elements of the feasibility study are described on the following page, and their values are shown in Figure 13. The text in the parentheses are the abbreviations used in Figure 13.

Technical - Number of Data Sources (TSRC)
Average Analysis Complexity (TCOM)
Number of Trips to Obtain Data (TTRP)
Element Execution (Yes/No) (TA)

Operational - Number Meetings for Interviews (OMT)
Number of Trips to Obtain Data (OTRP)
Element Execution (Yes/No) (OA)

Economic - Amount of Data Required (EDAT)
Complexity of Calculations (ECOM)
Element Execution (Yes/No) (EA)

Two other abbreviations used in Figure 13 are ID, which is a numerical identification which the author assigned based on increasing values of actual completion time, and HRS, which are the actual hours recorded for each feasibility study.

The information in Figure 13 provides some insight into the large variance in the time required to complete feasibility studies for a variety of projects. This variance appears to be attributable to the characteristics of the elements comprising the task.

An analysis was also performed on the data to determine those tasks which were most similar. This was a cluster analysis performed using STATGRAPHICS.

ID	HRS	QA	TA	EA	TSRC	TCOM	TTRP	QTRP	QMT	EDAT	ECON
23	2370	1	1	1	3	2	1	2	2	4	5
20	1266	1	1	1	2	1	1	1	1	3	3
09	290	0	1	1	2	1	1	0	0	2	3
01	48	0	0	1	0	0	0	0	0	2	2
16	838	1	1	1	3	4	1	0	2	2	3
24	4133	1	1	1	3	2	1	4	4	4	4
04	200	0	1	1	3	4	1	0	0	3	1
06	236	0	1	1	3	4	1	0	0	2	2
18	1166	1	1	1	2	1	1	1	1	2	2
11	483	0	1	1	2	3	2	0	0	3	2
13	673	0	1	1	3	4	2	0	0	4	3
22	1650	1	1	1	2	2	2	1	1	4	4
19	1220	1	1	1	3	1	1	1	1	3	3
10	352	0	1	1	2	1	1	0	0	3	3
08	263	0	1	1	2	1	1	0	0	2	2
21	1463	1	1	1	2	3	1	1	1	4	4
17	1112	1	1	1	2	1	1	1	1	1	2
14	776	0	1	1	3	3	2	0	0	6	3
15	835	1	1	1	3	4	1	0	2	2	3
07	261	0	1	1	2	1	1	0	0	2	2
12	605	0	1	1	4	1	2	0	0	7	2
05	234	0	1	1	3	4	1	0	0	2	2
03	92	0	0	1	0	0	0	0	0	4	2
02	68	0	0	1	0	0	0	0	0	2	3

Figure 13. Company A: Task Analysis

The results of this analysis are presented in Figure 14. For each task, the group to which it belongs is identified, along with the hours; and, for each cluster, the number of members is given, the percentage of all observations in that cluster, and the standard deviation of hours for all tasks in that cluster group.

Observ.	Cluster	Hrs.	Group	Freq.	Perc.	Std.
Obs. 1	1	2370	1	3	12.50	391.01
Obs. 2	7	1266	2	3	12.50	17.98
Obs. 3	5	290	3	2	8.33	1.50
Obs. 4	2	48	4	1	4.17	0.00
Obs. 5	3	838	5	8	33.33	84.27
Obs. 6	4	4133	6	3	12.50	70.30
Obs. 7	5	200	7	4	16.67	57.73
Obs. 8	5	236	FOR ALL OBSERVATIONS #OBSERVATIONS = 24 MEAN HOURS = 859.75 VARIANCE = 794735.77 STD. DEV. = 891.48			
Obs. 9	7	1166				
Obs. 10	5	483				
Obs. 11	6	673				
Obs. 12	1	1650				
Obs. 13	7	1220				
Obs. 14	5	352				
Obs. 15	5	263				
Obs. 16	1	1463				
Obs. 17	7	1112				
Obs. 18	6	776				
Obs. 19	3	835				
Obs. 20	5	261				
Obs. 21	6	605				
Obs. 22	5	234				
Obs. 23	2	92				
Obs. 24	2	68				

Figure 14. Company A: Cluster Analysis

The next step in the work analysis is to determine the type of output. For the three elements the modified SAT is shown below.

VERB	OBJECT	WORKER FUNCTION
Analyze	Technical Feasibility	D2
Analyze	Operational Feasibility	D2
Analyze	Economical Feasibility	D2

The worker functions shown in Figure 3 indicate that the verb "Analyze" has as its object DATA and that it is the third highest level of complexity within that category. Figure 6 further indicates that the classification for this work unit is "Information Processing." The expected results for these elements are also considered to be intangible, as supported by Figure 7.

This is the culmination of the work analysis. The results of this analysis (namely, the measurement and reporting levels, along with the type of output and classification) are now inputs for determining the most appropriate measurement technique.

Step Two: Choose the Measurement Technique

The measurement technique provides a vehicle for determining the amount of effective work in a specific work unit, which in this case, has been found to be the element. As previously stated, the choice of the most appropriate measurement technique depends on several variables: frequency, cycle, complexity, and variability. Also, the literature reveals that each type of work displays certain levels of these variables.

In step one, we found that each of the elements has the worker function of D2, which has a classification of

"Information Processing," which is a knowledge worker work unit. Table 10 indicates that the level of complexity for work units in this class range from complex to highly complex, and that their level of variability generally is highly variable. Also, the literature reveals that knowledge work tends to have low frequency, at best; and, if it exhibits a cycle, it is usually irregular. Thus, the characteristics of these elements are:

FREQUENCY: LOW or ONCE;

CYCLE: IRREGULAR or SPORADIC;

COMPLEXITY: COMPLEX or HIGHLY COMPLEX; and

VARIABILITY: HIGHLY VARIABLE.

The decision table in Figure 8 is used to determine the technique most suitable for this type of work. Four rules in the table possibly apply; however, the cluster analysis in Figure 13 indicates that groups of similar tasks have occurred at the installation more than once. Hence, the three rules which most represent this work are Rules 2, 17, and 20 - all of which recommend Historical Data as the technique technique.

Step Three: Apply the Measurement Technique

The chosen technique is historical data. The historical data which was collected was presented earlier

in Figure 12. The steps of the historical data technique were detailed in Table 11 in the previous chapter.

Application of those steps to the data has the following results:

Step 1: Analyze records (See Figure 12).

Step 2: Measure central tendency.

#OBSERVATIONS = 24

MEAN HOURS = 859.75

VARIANCE = 794735.77

STD. DEV. = 891.48

Step 3: Select output and correlate input to output.

The output for each element is a report. The time to complete each task is based on the elements it contains. Traditionally, the absence or presence of any one of the elements would be the only correlation between the input and the output. The results from this traditional approach would yield the following equation:

$$\text{Time} = 69.33 \text{ EA} + 328.21 \text{ TA} + 1207.75 \text{ OA},$$

where EA indicates an Economic Analysis; TA, a Technical Analysis; and OA, an Operational Analysis. Thus, for feasibility studies consisting only of economic analyses, the expected completion time is 69.33 hours; for those consisting of both an economic analysis and a technical analysis, 397.54 hours; and for those consisting of all three, 1605.29. Table 14 presents a comparison of these

expected times and the actual times, and a row which shows the amount by which the estimate exceeds or underestimates the actual task completion time.

Step Four: Determine Work Unit Parameters

The information contained in Table 14 shows much variance between the actual hours of the task and the hours which would be expected based on the measurement. This indicates that other information is needed before the target time can be determined. This additional information pertains to the parameters of the elements which affect the completion time.

Table 14

Actual Time vs Measurement Time

TASK ID	23	20	09	01	16	24	04	06	18
ACT. HRS.	2370	1266	290	48	838	4133	200	236	1166
MEAS. HRS.	1605	1605	397	69	1605	1605	397	397	1605
(MEAS-ACT)	-765	+339	+107	+21	+767	-2528	+197	+161	+439

TASK ID	11	13	22	19	10	08	21	17
ACT. HRS.	483	673	1650	1220	352	263	1463	1112
MEAS. HRS.	397	397	1605	1605	397	397	1605	1605
(MEAS-ACT)	-86	-276	-45	+385	+45	+134	+142	+493

TASK ID	14	15	07	12	05	03	02
ACT. HRS.	776	835	261	605	234	92	68
MEAS. HRS.	397	1605	397	397	397	69	69
(MEAS-ACT)	+379	-770	-136	+208	-163	+23	-1

It was previously concluded that the object of each of the elements is Data, and the object parameters suggested for Data in Table 13 are Amount, Complexity, and Presentation. With these parameters included in the model, the target time can be determined.

Step Five: Develop Target Time

Since the measurement level, element, is lower than the reporting level, task, the target is developed by implicit improvement of the measurement time through inclusion of other factors (parameters) which affect the completion time. The K-multipliers, then, will be developed with regression analysis, which is preceded by an interpretive analysis of the variables.

The first step of this analysis is to determine the degree of linear association among the variables. Figure 15 depicts the upper triangular form of the covariance matrix, which is symmetrical (i.e., $cor_{ij} = cor_{ji}$). Note that the covariance of the factor "EA" is zero with all other factors; this is valid since "EA" is a constant and has no variance. The correlation matrix is also determined and is depicted in Figure 16. Note that the constant factor "EA" has been omitted.

	ta	ea	tsrc	tcom	ttrp	otrp	omt	edat	ecom	hrs	oa
ta	.114 (24)	.000 (24)	.073 (24)	.086 (24)	.063 (24)	.033 (24)	.023 (24)	.022 (24)	.039 (24)	103.10 (24)	.054 (24)
ea		.000 (24)	.000 (24)	.000 (24)	.000 (24)	.000 (24)	.000 (24)	.000 (24)	.000 (24)	.000 (24)	.000 (24)
tsrc			.067 (24)	.08 (24)	.050 (24)	.022 (24)	.018 (24)	.036 (24)	.024 (24)	77.72 (24)	.027 (24)
tcom				.232 (24)	.043 (24)	-0.022 (24)	.018 (24)	.005 (24)	.069 (24)	26.13 (24)	.014 (24)
ttrp					.054 (24)	.005 (24)	.004 (24)	.06 (24)	.01 (24)	44.19 (24)	.009 (24)
otrp						.217 (24)	.10 (24)	.029 (24)	.106 (24)	409.39 (24)	.152 (24)
omt							.068 (24)	.00 (24)	.06 (24)	212.27 (24)	.108 (24)
edat								.219 (24)	.056 (24)	104.64 (24)	-.024 (24)
ecom									.241 (24)	254.48 (24)	.10 (24)
hrs										829290 (24)	324.15 (24)
oa											0.254 (24)

Figure 15. Company A: Covariance Matrix

	ta	tsrc	tcom	ttrp	otrp	omt	edat	ecom	hrs	oa
ta	1.000 (24)	.8417 (24)	.5345 (24)	.7969 (24)	.207 (24)	.2625 (24)	.1375 (24)	.2377 (24)	.3351 (24)	.3194 (24)
tsrc		1.000 (24)	.6415 (24)	.8392 (24)	.1807 (24)	.273 (24)	.3001 (24)	.1878 (24)	.3308 (24)	.2091 (24)
tcom			1.000 (24)	.3889 (24)	-.0968 (24)	.1445 (24)	.0214 (24)	.2913 (24)	.0596 (24)	.0598 (24)
ttrp				1.000 (24)	.0502 (24)	.0637 (24)	.5447 (24)	.0894 (24)	.209 (24)	.0775 (24)
otrp					1.000 (24)	.828 (24)	.1328 (24)	.4632 (24)	.9642 (24)	.6481 (24)
omt						1.000 (24)	.005 (24)	.4704 (24)	.8951 (24)	.8219 (24)
edat							1.000 (24)	.2445 (24)	.2455 (24)	-.1025 (24)
ecom								1.000 (24)	.5694 (24)	.4068 (24)
hrs									1.000 (24)	.7068 (24)
oa										1.000 (24)

Figure 16. Correlation Matrix

Next, a factor analysis was performed to further confirm the factors which should be used to determine the task completion time, assuming linear relationships. The Spearman approach was used to perform the factor analysis. It uses a correlation analysis to determine

the interaction among the variables and a covariance analysis to measure the linear associations among the variables. The results of this analysis are shown in Figure 17.

The heading "Communalities" on a. and c. reports that portion of the variance of the dependent variable, hours, which is accounted for exclusively by factor i. However, the communalities in 17c. is a revision of those shown in 17a. that estimates the proportion of the variability of each variable that is based on common factors. The eigenvalues shown in a. are proportional to the variance accounted for by each of the factors. The factor loading, shown in b., is the importance of the individual factor on the value of the dependent variable.

This analysis reveals that 100% of the variance of the dependent variable is attributable to the first six factors. An analysis of the factor matrix further indicates that the model should include otrp and omt.

Since neither the exact form of the regression model nor the appropriate independent variables (the factors) are perfectly known, a stepwise regression was performed on the data to optimally determine the model which best predicted the hours of the task.

(17a)

Variable	Communality	Factor	Eigenvalue	% Var	Cum %
ta	0.86522	1	4.27611	48.5	48.5
tsrc	0.88282	2	2.52504	28.6	77.1
tcom	0.70288	3	.99460	11.3	88.4
ttrp	0.93645	4	.62779	7.1	95.5
otrp	0.99294	5	.20643	2.3	97.8
omt	0.97227	6	.19540	2.2	100.0
edat	0.80067	7	-.00521	.0	100.0
ecom	0.77279	8	-.03322	.0	100.0
hrs	0.99673	9	-.05041	.0	100.0
oa	0.75197	10	-.06177	.0	100.0

(17b) Factor Matrix

Var./Factor	1	2	3	4	5	6
ta	0.65832	-0.58104	-0.22785	-0.13527	-0.16499	-0.13878
tsrc	0.65770	-0.66498	-0.11811	-0.07688	-0.13719	-0.00652
tcom	0.36208	-0.51172	-0.38336	0.37395	0.19765	0.04237
ttrp	0.52620	-0.76140	0.22007	-0.21369	-0.10409	0.03953
otrp	0.77871	0.52469	0.15939	-0.14817	0.11804	-0.23368
omt	0.82751	0.45835	-0.15340	-0.04881	0.10068	0.23662
edat	0.28275	-0.31189	0.77277	0.12258	0.03598	0.13983
ecom	0.58402	0.15885	0.08738	0.60377	-0.18288	-0.08370
hrs	0.90035	0.38892	0.16057	-0.04186	0.07852	-0.07273
oa	0.69236	0.38012	-0.23196	-0.11143	-0.21333	0.17405

(17c)

Variable	Est Communality	Variable	Est Communality
ta	0.88769	omt	0.98690
tsrc	0.91349	edat	0.81028
tcom	0.72062	ecom	0.77894
ttrp	0.96311	hrs	1.00088
otrp	0.99759	oa	0.76587

Figure 17. Company A: Factor Analysis Results

This procedure was accomplished with the statistical package called SAS. The regression analysis was performed as projects occurred and on the entire set of data. The summary of results from the regression analyses is presented in Figure 18. The column, "As Occur Hours," begins with observation 12 because this is the minimum number of observations for which a model could be determined given the number of independent variables. (In general, the number of observations must outnumber the number of independent variables by two.) The "Residuals" are the Actual Hours - As Occur/Model Hours; and the "Standardized Residuals" are the normalized values of the residuals. The actual runs to determine the "As Occur" models is presented in Appendix C1, and the results from the analysis of the entire model is presented in Appendix C2. The output from these runs contains the model description (the coefficient values); the Analysis of Variance; and the regression results, which consists of the observed values, the fitted values, and the residuals.

Information presented in the ANOVA was used to determine the goodness of fit of the model to the data. The F value calculated by the ANOVA (663.01) was compared to a critical F value of 3.10 (at a level of significance 0.05 with (3,20) degrees of freedom) to test the

TASK ID	HOURS			RESIDUALS		STD. RESIDUALS	
	ACTUAL	OCCUR	MODEL	OCCUR	MODEL	OCCUR	MODEL
23	2370	----	2242.8	----	127.2	----	1.42
20	1266	----	1274.7	----	-8.7	----	-0.09
09	290	----	306.6	----	-16.6	----	-0.18
01	48	----	6.8	----	41.2	----	0.48
16	838	----	836.5	----	1.5	----	0.02
24	4133	----	4179.0	----	-46.0	----	-0.81
04	200	----	306.6	----	-106.6	----	-1.13
06	236	----	306.6	----	-70.6	----	-0.75
18	1166	----	1274.7	----	-108.7	----	-1.15
11	483	----	606.3	----	-123.3	----	-1.14
13	673	----	606.3	----	66.7	----	0.75
22	1650	1649.8	1574.4	.2	75.6	-0.17	0.85
19	1220	1219.7	1274.7	.3	-54.7	-0.16	-0.58
10	352	349.3	306.6	2.7	45.4	0.05	0.48
08	263	251.5	306.6	11.5	-43.6	0.83	-0.46
21	1463	1438.1	1274.7	24.9	188.3	2.02	1.99
17	1112	1110.3	1274.7	1.7	-162.7	-0.04	-1.72
14	776	770.4	606.3	5.6	169.7	0.31	1.91
15	835	836.5	836.5	-1.5	-1.5	-0.32	-0.02
07	261	248.2	306.6	12.8	-45.6	0.95	-0.48
12	605	603.7	606.3	1.3	-1.3	-0.07	-0.01
05	234	238.3	306.6	-4.3	-72.6	-0.57	-0.77
03	92	115.8	6.8	-23.8	85.2	-2.30	0.98
02	68	73.8	6.8	-5.8	61.2	-0.71	0.71

* None of the residuals are beyond 3 sigma limits

Figure 18. Company A: Regression Analysis Results

hypothesis that all the coefficients are equal to zero, and thus are insignificant. Since F is greater than the critical F value, the hypothesis is rejected. Likewise, the T-test for each individual parameter shows all coefficients to be significant, except that of the intercept.

Another important value presented in the Regression results and in the ANOVA is R-Squared. The value of 0.99

implies that the factors in the model are those which explain almost all of the variance of the dependent variable, hours.

The model found to determine the target time for any task similar to these studied is

$$\begin{aligned} \text{HOURS} = & 6.64 \text{ EA} + 299.72 \text{ TTRP} + 703.13 \text{ OTRP} \\ & + 264.97 \text{ OMT.} \end{aligned}$$

This model differs greatly from the model determined from the measurement. Instead of including TA and OA, it includes parameters of these elements. A comparison among the actual hours, the measurement hours, and the target hours is presented in Figure 19.

An analysis of the data in this figure reveals that the target time more closely approximates the actual time for 18 of the 24 tasks. Those tasks in which the target hours significantly differed from the actual time were those which consisted only of the economical analysis.

The same methodology was also applied to a second set of data from an organization at Company B. Although the work performed at Company B differs from that performed at Company A, both sets of data represent knowledge work and demonstrate the validity of the methodology offered by this research.

TASK ID	23	20	09	01	16	24	04	06	18
ACT. HRS.	2370	1266	290	48	838	4133	200	236	1166
MEAS. HRS	1605	1605	397	69	1605	1605	397	397	1605
TARG. HRS	2243	1275	306	7	837	4179	306	306	1275

TASK ID	11	13	22	19	10	08	21	17
ACT. HRS.	483	673	1650	1220	352	263	1463	1112
MEAS. HRS	397	397	1605	1605	397	397	1605	1605
TARG. HRS	606	606	1574	1274	306	306	1274	1274

TASK ID	14	15	07	12	05	03	02
ACT. HRS.	776	835	261	605	234	92	68
MEAS. HRS	397	1605	397	397	397	69	69
TARG. HRS	606	837	306	606	306	7	7

Figure 19. Company A: Actual vs Measurement vs Target Time

Company B Application

Step One: Heirarchical Structuring of the Work

Company B is a government corporation, which performs work at several installations by many divisions. The work structure of this Company is presented in Figure 20.

The next operation in the work analysis is to determine the reporting level. The hours are reported at the completion of each phase rather than at the end of a set period. Thus, for this company, the measurement

8th Order Work Unit (Global End):	Company Strategic Goals
7th Order Work Unit (Intermediate Goal):	Division Goals
6th Order Work Unit (Program):	Section Goals
5th Order Work Unit (Mission):	MIS Development
4th Order Work Unit (Job):	Module Development
3rd Order Work Unit (Task):	Phase 3 Analysis
2nd Order Work Unit (Element):	Administrative Procedures Computer Procedures Computer Programs Interviews
1st Order Work Unit (Behavior):	Can Not Be Determined

Figure 20. Company B: Work Structure

level is the element and the reporting level is the task. Thus, the target time will again be developed with an implicit improvement of the measurement time.

The data collected by and received from the Systems Analyst were the hours expended to perform Phase 3 of nine of the modules of the system, a description of the modules, and a description of the work performed during that phase. This data is presented in Figure 21.

An analysis was also performed on the data to determine the amount of variance among those tasks which were most similar. This was a cluster analysis performed using STATGRAPHICS. The results of this analysis are presented in Figure 22. For each task, the cluster to which it belongs is identified, along with the hours; and, for each cluster, the number of members (frequency) is given, and the percentage of all observations in that cluster.

Also, the covariance matrix and the correlation matrix were determined, and a factor analysis was performed on the data. The results of these analyses are presented in Figures 23, 24, and 25, respectively.

ID	HOURS	APROCS	CPROCS	PROGS	INTRVWS	ACOMP	CCOMP	PCOMP
61	37	2	1	1	2	2	2	1
59	30	1	2	4	1	2	2	2
65	46	0	1	3	3	0	2	2
66	48	0	1	2	4	0	2	1
29	62	2	1	3	4	4	3	3
64	25	0	1	1	2	0	2	3
09	143	0	10	4	4	0	3	4
18	12	2	1	0	1	2	1	0
10	132	4	4	5	2	4	2	3

KEY:

ID - Module ID

HOURS - Actual Phase 3 Hours

APROCS - Administrative
Procedures

CPROCS - Computer Procedures

PROGS - Computer Programs

INTRVWS - User Procedures

ACOMP - Complexity of
Administrative
Procedures

CCOMP - Complexity of Computer
Procedures

PCOMP - Complexity of Computer
Programs

Figure 21. Company B: Task Analysis

Observ.	Cluster	Hrs.	Group	Freq.	Perc.
Obs. 1	1	37	1	6	66.67
Obs. 2	1	30	2	2	22.22
Obs. 3	1	46	3	1	11.11
Obs. 4	1	48			
Obs. 5	1	62			
Obs. 6	1	25			
Obs. 7	2	143			
Obs. 8	3	12			
Obs. 9	2	132			

Figure 22. Company B: Cluster Analysis

	hours	aprocs	cprocs	progs	intrvws	acom	ccomp	pcomp
hours	2171.5 (9)	15.7 (9)	117.5 (9)	58.3 (9)	26.6 (9)	12.7 (9)	16.7 (9)	42.1 (9)
aprocs		1.9 (9)	-0.4 (9)	0.5 (9)	-0.6 (9)	2.1 (9)	-0.1 (9)	0.1 (9)
cprocs			9.0 (9)	2.7 (9)	1.22 (9)	-0.8 (9)	0.9 (9)	2.4 (9)
progs				2.8 (9)	0.5 (9)	0.8 (9)	0.6 (9)	1.4 (9)
intrvws					1.5 (9)	-0.5 (9)	0.6 (9)	0.7 (9)
acom						2.8 (9)	0.1 (9)	0.1 (9)
ccomp							0.4 (9)	0.6 (9)
pcomp								1.6 (9)

Figure 23. Company B: Covariance Matrix

	hours	aprocs	cprocs	progs	intrvws	acom	ccomp	pcomp
hours	1.00 (9)	.24 (9)	.84 (9)	.75 (9)	.46 (9)	.16 (9)	.60 (9)	.71 (9)
aprocs		1.00 (9)	-.08 (9)	.21 (9)	-.37 (9)	.91 (9)	-.18 (9)	-.09 (9)
cprocs			1.00 (9)	.54 (9)	.33 (9)	-.16 (9)	.52 (9)	.64 (9)
progs				1.00 (9)	.26 (9)	.28 (9)	.55 (9)	.68 (9)
intrvws					1.00 (9)	-.23 (9)	.75 (9)	.43 (9)
acom						1.00 (9)	.06 (9)	.03 (9)
ccomp							1.00 (9)	.80 (9)
pcomp								1.00 (9)

Figure 24. Company B: Correlation Matrix

25a.

Variable	Communality	Factor	Eigenvals	%Var	Cum%
hours	0.99987	1	3.99648	50.1	50.1
aprocs	0.99983	2	2.19885	27.6	77.7
cprocs	0.99937	3	.83888	10.5	88.2
progs	0.99819	4	.47616	6.0	94.2
intrvws	0.99922	5	.31262	3.9	98.1
acomp	0.99957	6	.13394	1.7	99.8
ccomp	0.98243	7	.01912	.2	100.0
pcomp	0.99720	8	-.00036	.0	100.0

25 b. Factor Matrix

Var/Factor	1	2	3	4	5
hours	0.89955	0.23322	-0.21688	-0.26122	-0.06353
aprocs	-0.03859	0.97436	0.03921	-0.18471	0.04802
cprocs	0.80200	-0.06951	-0.49551	-0.22676	0.15619
progs	0.78490	0.33161	-0.11525	0.28960	-0.41392
intrvws	0.63725	-0.43513	0.51734	-0.33179	-0.14381
acomp	0.04413	0.93231	0.32166	0.00641	0.08600
ccomp	0.85797	-0.14653	0.40047	0.10575	0.15379
pcomp	0.88452	-0.01681	-0.00339	0.34236	0.24253

25 c.

Variable	Est. Communality
hours	0.98289
aprocs	0.98882
cprocs	0.96938
progs	0.99451
intrvws	0.99384
acomp	0.98205
ccomp	0.95279
pcomp	0.95870

Figure 25. Company B: Factor Analysis Results

Next, the type of output is determined for the four elements by using the modified SAT as follows:

<u>VERB</u>	<u>OBJECT</u>	<u>WORKER FUNCTION</u>
Write	Administrative Procedures	D5
Write	Computer Procedures	D5
Write	Computer Programs	D5
Conduct	User Interviews	D1

The worker function synonyms in Table 6 indicate that the verb "Write" has as its object DATA and that it is the fifth level of complexity within that category. The synonyms in Table 7 indicate that "Conduct" also has DATA as its object and it is the second highest level of complexity. From Figure 6, it is surmised that these elements involve the processing and the dissemination of information; and Figure 7 indicates that the results are tangible for the first three elements and intangible for the latter.

This culminates the work analysis. The results of this analysis (namely, the measurement and reporting levels, along with the type of output and classification) are now inputs for determining the most appropriate measurement technique.

Step Two: Choose the Measurement Technique

Step one revealed that three of the elements have the worker function of D5. Table 10 indicates that the level of variability for work units in this class range from constant to variable and that their level of complexity generally is complex. Thus, these characteristics, and those of knowledge work described in the literature, provide the following description of these elements: Frequency, low or once; Cycle, irregular or sporadic; Complexity, complex; and Variability, constant to variable.

For the D1 element, the frequency and cycle are assumed to be the same; but Table 10 indicates that the Complexity is complex, and the Variability is highly variable.

The decision table in Figure 8 is used to determine the technique most suitable for these two types of work. Rule 17 seems to be the most appropriate technique for both of these classes of elements. The technique recommended by this rule is Historical Data.

Step Three: Apply the Measurement Technique

The chosen technique is historical data. The historical data which was collected was presented earlier in Figure 21. The steps of the historical data technique

were detailed in Table 11 in the previous chapter.

Application of those steps to the data has the following results:

Step 1: Analyze records (See Figure 21).

Step 2: Measure central tendency.

#OBSERVATIONS = 9

MEAN HOURS = 59.44

MEDIAN = 46

MODE = 37

VARIANCE = 2171.53

STD. DEV. = 46.608

(For all other variables, See Figure 26.)

Step 3: Select output and correlate input to output.

VARIABLE	MEAN	MEDIAN	MODE	VARIANCE	STD. DEV.
HOURS	59.44	46.00	None	2171.53	15.53
APROCS	1.22	1.00	0.00	1.94	1.39
CPROCS	2.44	1.00	1.00	9.03	3.00
PROGS	2.56	3.00	1.00	2.78	1.67
INTRVWS	2.56	2.00	2.00	1.53	1.24
ACOMP	1.56	2.00	0.00	2.78	1.67
CCOMP	2.11	2.00	2.00	0.36	0.60
PCOMP	2.11	2.00	3.00	1.61	1.27

Figure 26. Company B: Descriptive Statistics

The output for each of the D5 elements is a set of instructions (either for the users, the operators, or the computer). The time to complete each task is based on the elements which are performed. The results from the application of the measurement yields the following equation:

$$\text{Hours} = 8.17 \text{ APROCS} + 10.01 \text{ CPROCS} + 5.69 \text{ PROGS} + 5.25 \text{ INTRVWS}$$

where APROCS is administrative procedures; CPROCS, computer procedures; PROGS, computer programs; and INTRVWS, user interviews. Table 15 presents a comparison of the expected times from the model and the actual times, and a row which shows the amount by which the estimate exceeds or underestimates the actual task completion time.

Table 15

Company B: Actual Time vs Measurement Time

ID	61	59	65	66	29	64	09	18	10
ACT. HRS.	37	30	46	48	62	25	143	12	132
MEAS. HRS	43	56	43	42	64	26	144	32	112
(MEAS-ACT)	+ 6	+26	- 3	- 6	+ 2	+ 1	+ 1	+20	- 20

Step Four: Determine Work Unit Parameters

The variance between the actual hours and the expected hours of the measurement indicates that other information is needed before the target time can be determined. This additional information pertains to the parameters of the elements which affect the completion time. It was previously concluded that the object of each of the elements is Data, and the object parameters suggested for Data in Table 12 are Amount, Complexity, and Presentation. For this set of data, the parameter with the most impact upon the completion time is Complexity.

Step Five: Develop Target Time

Since the measurement level, element, is lower than the reporting level, task, the target is developed by implicit improvement of the measurement time through inclusion of other factors (parameters) which affect the completion time. However, in determining the target completion time of this task, only those factors which are necessary to produce the variance in the time should be considered. Since the number of observations is small, this was accomplished sufficiently with the stepwise regression function of STATGRAPHICS.

The regression analyses were performed as tasks occurred and on the entire set of data. The summary of results from the regression analyses is presented in Figure 27. The column, "As Occur Hours," begins with observation number 6 because this is the minimum number of observations for which a model could be determined given the number of independent variables. The "Residuals" are the Actual Hours - As Occur/Model Hours; and the "Standardized Residuals" are the normalized values of the residuals. The actual runs to determine the models as the data occurred is presented in Appendix D1. The output from these runs contains the model description (the coefficient values); the Analysis of Variance; and the regression results, which consists of observed values, fitted values, and the residuals.

TASK ID	HOURS			RESIDUALS		STD. RESIDUALS	
	ACTUAL	OCCUR	MODEL	OCCUR	MODEL	OCCUR	MODEL
61	37	----	49.45	---	-12.45	----	- 0.74
59	30	----	42.14	---	-12.14	----	-0.68
65	46	----	35.28	---	10.72	----	0.66
66	48	----	43.17	---	4.83	----	0.34
29	62	62.07	65.23	-0.07	-3.23	-0.02	-0.22
64	25	29.31	27.39	-4.31	-2.39	-0.99	-0.14
09	143	142.83	147.63	0.17	-4.63	2.29	-1.11
18	12	14.00	41.56	-2.00	-29.56	-0.36	-1.75
10	132	130.49	106.34	1.51	25.66	0.21	2.29

Figure 27. Company B: Regression Analysis Results

The results of the stepwise regression of the development of the entire model is found in Appendix D2. It was run with the statistical package SAS.

Information presented in the ANOVA was used to determine the goodness of fit of the model to the data. The F value calculated by the ANOVA, 46.91, far exceeds the critical F value at a level of significance 0.05 with (3,6) degrees of freedom, 4.76, so the hypothesis that all the coefficients are equal to zero, and thus are insignificant is rejected. Also, the analysis of the Parameter Elements indicated that the individual coefficients are significant at 0.05.

The R-Squared value of .9591 presented in the ANOVA indicates that over 95% of the variance experienced by the dependent variable is attributable to the variables included in the model.

The model found to determine the target time for any task similar to those of Company B is

$$\text{HOURS} = 11.03 \text{ APROCS} + 11.61 \text{ CPROCS} + 7.89 \text{ INTRVWS}$$

This model differs from the model determined from the measurement in that it contains one less variable, PROGS. A comparison among the actual hours, the measurement hours, and the target hours is presented below in Figure 28.

ID	61	59	65	66	29	64	09	18	10
ACT. HRS.	37	30	46	48	62	25	143	12	132
MEAS. HRS	43	56	43	42	64	26	144	32	112
TARG. HRS	49	42	35	43	65	27	147	41	106

Figure 28. Company B: Actual vs Measurement vs Target Time

In the previous figure, the target time more closely approximates the actual time for only one of the tasks. The small number of observations does not lend itself to the development of a precise model. However, as more data becomes available, the resulting models should more accurately predict the time.

The previous two applications involved implicit development of the target time. Explicit development is also viable with the prescribed methodology. For example, if Company B's management wanted a target time specifically for the element "Write Computer Programs," the time could be developed as follows:

$$\text{HOURS} = (\text{AVG. TIME}) * \text{SUM}(\text{PARAMETER}_i \text{ VAL}_n / \text{VAL}_a)$$

where VAL_n is the value of the parameter of the task for which the target is being determined now, and VAL_a is the average value of the parameter.

Suppose an analysis of the historical data reveals an average of 5.75 hours per program written, and Figure 23 gives the average program complexity (progcomp) as 2.11 out of 10. (This complexity value is a subjective measure, but with knowledge work subjective measures must often be included in calculations.) For a project with an expected complexity level of 7, the target time is calculated as

$$\begin{aligned}\text{Hours} &= 5.75 \text{ Hours} * (7/2.11) \\ &= 5.75 * 3.3175 = 19.08.\end{aligned}$$

Hence, the methodology applies to work in which the the reporting level is higher than the measurement level and to work in which the reporting and measurement levels are the same. (Work measurement for control and management would not be expected to provide feedback, which enables control, for a system in which the measurement level is higher than the reporting level.)

General conclusions and improvement recommendations, along with a discussion of the assumptions and limitations of the methodology and its application, are provided in the next chapter.

CHAPTER V

SUMMATION

Summary

The impetus for measuring knowledge work is the necessity to control and manage it. Where there is no measurement, there can be little control. If management has no standards against which to compare worker's performance with regard to productivity, management cannot assess how well individual workers have performed. Also, management needs to know how to assign work, and how much work an individual can reasonably be expected to perform. Therefore, contrary to popular opinion, the measurement is not a tool used by management against the employee, but rather a yardstick which benefits both the employee and management.

The work performed by knowledge workers differs from the work which traditionally has been considered measurable. First, it entails a significant amount of cognitive ability, as opposed to skill-based activities; secondly, it rarely produces a tangible output; and thirdly, the work is not patterned or effectively decomposable. These characteristics render many of the techniques used for measuring blue-collar work inapplicable.

The cognitive content of knowledge work prohibits the application of predetermined or standard time systems which are based on the measurement and aggregation of elemental motions. Most of the actions of knowledge work are invisible to the observer because they are primarily mental. Secondly, with knowledge work, the unit of its accomplishment is rarely a tangible and directly countable output. It is either a nonphysical contribution toward producing a tangible output, information which has resulted from the processing of data, or a tangible output, such as a report, for which the countability lies in the content and not in its number or size. Thirdly, since knowledge work tends to be irregular in nature, those techniques which simply examine one cycle and then multiply the results by the number of cycles are useless in measuring knowledge work. Another characteristic which tends to render such techniques useless is that knowledge work is noncyclical and highly variable from one occurrence to another.

Another problem in the application of classical approaches is that they require any application of work measurement to be preceded by a method study. The premise behind this requirement is that there is no point in setting a standard time on a job which is being performed in an ineffective way. This premise should

hold true for any type of work. However, with knowledge work, it is often impossible to clearly define a unique way of performing a task. The solution then is not to define a unique manner to perform the work, but to ensure that the methods being applied are both efficient and effective.

In practice, the tendency is to reverse this philosophy by making a quick determination of labor utilization, reducing the staff to efficient proportions so that payroll savings become immediately apparent, and then looking at ways of improving the methods. Thus, industry tends to "back" methods improvement into the process rather than build it in. With the work analysis offered in this research, a structured process exists for examining the work being performed, so that management can readily determine whether or not the work is contributing to the goals of the work unit and, consequently, whether it should be measured.

This research addresses many of these problems. It provides a methodology which permits the quantitative description, analysis, and measurement of knowledge work for the purpose of productivity measurement. The methodology includes a structure for classifying work and provides a framework for determining the level at which work should be controlled (based on the frequency of

reporting), the level at which the work should be measured to provide feedback for the chosen level of control, and for choosing the most appropriate measurement technique for the type of work in question. It also provides a means for determining how the target is to be calculated (as a factor of the amount and type of aggregation required from the measurement level to the control or reporting level).

The approach taken involves three phases: (1) information gathering, (2) development, and (3) testing and refinement. The first phase consists of a literature review and an industry survey. During the second phase, procedures for classifying work and for selection and application of measurement techniques are developed, along with algorithms for determining the target time; and the third phase presents the application of the methodology at two local companies.

Conclusions

The two applications of the methodology successfully followed the outlined steps. As a result of these tests, some of the advantages and disadvantages of the methodology became apparent.

Advantages of the methodology are:

1. It provides target times for completion of work units, thus yielding a time which might be a positive incentive to employees rather than a negative standard which they feel is a management device to use against them.

2. Although the target is not based solely on objective measures), it does provide a time which is reflective of the nature of the work.

3. Work can be scheduled, and then controlled, more accurately from the time target; and the work load might be more evenly distributed over the staff.

4. Also, if payrolls must be reduced, the reductions can be to a degree which will ensure effective working (due to the work analysis built into the process) at an efficient level.

The effectiveness of this process is reflected in some of its features:

1. It is flexible enough to deal with the measurement of work with a variety of characteristics; particularly, work which has an extreme range of variation inherent in its tasks or other work units. This flexibility is offered in the decision table presented in Table 8.

2. It provides a means for identifying the units of output to be counted, with regard to the time consumed. This is accomplished with the classification system.

3. It provides a method of determining where in the hierarchy the reporting back should occur. This feedback allows the modification of the input to obtain the desired effect at the output. If this feedback is removed or not received where it can be most effective, the control is lost. In work measurement, once the targets have been derived, results must be monitored so that personnel levels may be constantly observed and adjusted. Afterall, it is not the work which is being measured but the time taken to perform the work; and, contrary to an often assumed relationship, the time taken is not directly proportional to the work performed.

Disadvantages are:

1. The identification of the parameters and their evaluations require a great deal of time and input from several parties. In some cases, although it is known that the named parameters do affect the completion time, records have not been kept which would allow their objective determination, so these values are often estimates. This subjective feature may be unavoidable.

2. The targets are improvements of the measurement times. The means of determining the model by which this improvement takes place requires some mathematical background, and even then may require some trial runs to determine the model which best predicts the completion times which have been observed (if using historical data or averages) or are within the range of what is expected as a result of past experience (if estimating).

These two disadvantages may be overcome through increased experience.

Recommendations

The limitations of this research represent impediments to the development and application of the methodology for classifying and measuring knowledge work. These limitations and the recommended responses are listed below.

1. The variety of job tasks inhibits the development of an all-encompassing work classification system.

Response: The work classifications system could be expanded by building upon and studying the characteristics of the seven areas of work identified by Beruvides in the literature.

2. While common elements exist among various knowledge worker tasks, no single set of measurement variables is universally applicable, and no single set of analytical tools can serve to interpret all the data.

Response: Since knowledge work tends to vary from occurrence to occurrence, the recommended approach is to study enough similar tasks (preferably at different organizations or companies) to identify the most significant variables, and then develop tools or enhance existing tools which effectively and reliably measure those variables based on their characteristics.

3. Much of the variance in the completion times of similar tasks is not explainable and is accepted as natural variation.

Response: In almost any process, some percentage of the variance is accepted as natural variation; however, a significant portion tends to be explainable, and it is that portion which must receive considerable attention.

4. Some intangible factors which are identified as affecting the task completion times have been addressed, but have been deemed nonquantifiable.

Response: At this stage of the research, it was deemed best to concentrate upon those factors which could be quantified analytically. However, the values of the

other factors are important in further reducing the observed time variances; thus, further research should be done to provide a means for quantifying those factors in an effective and unbiased manner. Also, it is accepted that many of the factors contributing to the measurement of knowledge work are intangible and apt to be highly subjective.

In spite of the areas not addressed, or not fully addressed by this research, the methodology presented does significantly answer many of the reasons offered for not measuring knowledge workers. Also, it provides a structured basis from which additional studies can be performed.

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APPENDIX A
INDUSTRY SURVEY LETTER

March 28, 1988

To the Industrial Engineering Department/Productivity
Center:

I am a doctoral candidate at the University of Tennessee in the Department of Industrial Engineering. My dissertation topic is "Performance Measurement and Evaluation of Knowledge Workers for Productivity Improvement". The purpose of this research is to develop a methodology for measuring all aspects of office work - knowledge work as well as manual work.

I am presently conducting a literature search and canvassing companies to determine approaches being used to measure white-collar productivity. I have identified 250 of the largest manufacturing and 250 of the largest service organizations to ascertain how industry is approaching this problem. I would appreciate your sharing with me a description of your approach to measuring the productivity of white-collar workers in general and knowledge workers in particular. It would also be of great benefit to me if you would send me a copy of your procedures or the manual which you are using. If this is not possible, would you send a summary of the procedures.

I look forward to your response by April 15, if at all possible; if not, as soon as you possibly can.

Sincerely,

Denise F. Jackson

APPENDIX B

DOT WORKER FUNCTION DEFINITIONS

DOT WORKER FUNCTION DEFINITIONS

A. FUNCTIONS WITH DATA

DATA: Data are intangible and include numbers, words, symbols, ideas, concepts, and oral verbalization; they are obtained by observation, investigation, interpretation, visualization, and mental creation.

SYNTHESIZE - Integrate analyses of data to discover facts and/or develop knowledge concepts or interpretations.

Create, Design, Develop, Establish, Formulate, Initiate, Originate

COORDINATE - Determine time, place, and sequence of operations or action to be taken on the basis of analysis of data.

Implement, Organize, Plan and Schedule

ANALYZE - Examine and evaluate data; present alternative actions in relation to the evaluation.

Appraise, Approve, Assess, Audit, Check, Decide, Examine, Evaluate, Interpret, Investigate, Review, Select, Study

COMPILE - Gather, collate, or classify information; report and/or carry out a prescribed action in relation to the information.

Classify, Collect, Interview, Observe, Review

COMPUTE - Perform arithmetic operations and report on and/or carry out a prescribed action in relation to them.

Calculate, Determine, Estimate, Figure

COPY - Transfer data from one medium to another.

Duplicate, Enter, Post, Record, Transcribe, Type

COMPARE - Judge the readily observable functional, structural, or compositional characteristics.

Examine, Grade, Inspect, Select, Sort, Standardize, Verify

B. FUNCTIONS WITH PEOPLE

PEOPLE: People are human beings or animals dealt with on an individual basis as if they were human.

MENTOR - Deal with individuals in terms of their total personalities in order to advise them with regard to problems that may be resolved by legal, scientific, clinical, spiritual, or other professional principles.
Advise, Counsel, Consult, Recommend

NEGOTIATE - Exchange ideas, information, and opinions with others to formulate policies and programs and/or arrive jointly at decisions, conclusions, or solutions.
Confer, Contact, Intercede, Mediate

INSTRUCT - Teach subject matter to others.
Coach, Demonstrate, Explain, Initiate, Lecture, Teach,
Train

SUPERVISE - Determine or interpret work procedures for a group of workers, assign duties, and other responsibilities.
Assign, Conduct, Control, Delegate, Direct, Guide, Manage

DIVERT - Amuse others.
Act, Entertain, Perform, Play, Sing

PERSUADE - Influence others in favor of a product, service, or point of view.
Authorize, Enlist, Influence, Motivate, Promote, Solicit,

SPEAK - Talk with and/or signal people to convey or exchange information.
Answer, Direct, Explain, Greet, Indicate, Inform, Interview, Present, Receive

SERVE - Attend to the needs or requests of people or animals or the expressed or implicit wishes of people.
Accompany, Administer, Assist, Carry, Contribute, Execute, Maintain, Participate, Provide

TAKE INSTRUCTIONS - Receive Orders [No Variety of Responsibility]

C. FUNCTIONS WITH THINGS

THINGS: Things are inanimate objects such as machines, tools, equipment, and products.

SETTING UP - Adjust machines or equipment to prepare them to perform their functions.

Adjust, Mount, Unlock

PRECISION WORKING - Use of the body or tools to place objects or materials in situations where responsibility for the attainment of standards occurs. [Considerable Judgement]

OPERATING/CONTROLLING - Start, stop, control, or adjust the progress of machines or equipment; or observing gauges or dials to control factors.

Regulate, Operate, Maintain

DRIVING/OPERATING - Start, stop, and control the actions of machinery or equipment for which a course must be steered, or which must be guided.

Drive, Operate, Turn

MANIPULATING - Use body members, tools, or special devices to work, move, guide, or place objects or materials.

[Some latitude for judgement with regard to precision attained]

TENDING - Start, stop, and observe the function of machines and equipment.

Maintain, [Little judgement to make adjustments]

FEEDING/OFFBEARING - Place materials in or remove them from machines or equipment which are automatic or tended or operated by other workers.

Insert, Dump, Load, Unload

HANDLING - Use body members, handtools, and/or special devices to work, move, or carry objects or materials.

[Little or no judgement with regard to attainment of standards or in selecting appropriate tools]

Carry, Distribute, Lift, Move, Use

APPENDIX C1

COMPANY A: AS-OCCURRED REGRESSION ANALYSES

Model fitting results for: 12.hours

Independent variable	coefficient	std. error	t-value	sig.level
12.econ	77.483146	138.112085	0.5610	0.5885
12.tttrips	275.102528	101.647742	2.7064	0.0241
12.otrips	952.418539	48.284392	19.7252	0.0000

R-SQ. (ADJ.) = 0.9861 SE= 194.231842 MAE= 118.866105 DurbWat= 1.792
 Previously: 0.9868 186.047930 113.012936 1.806
 12 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	29614429.	3	9871476.	261.662	.0000
Error	339534.	9	37726.0		
Total	29953963.	12			

R-squared = 0.988665

R-squared (Adj. for d.f.) = 0.986146

Std. error of est. = 194.232

Durbin-Watson statistic = 1.79181

Regression results for 12.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2257.42	112.577	0.57960
2	1266.00	1305.00	-39.0042	-0.20081
3	290.000	352.586	-62.5857	-0.32222
4	48.0000	77.4831	-29.4831	-0.15179
5	838.000	352.586	485.414	2.49915
6	4133.00	4162.26	-29.2598	-0.15064
7	200.000	352.586	-152.586	-0.78559
8	236.000	352.586	-116.586	-0.60024
9	1166.00	1305.00	-139.004	-0.71566
10	483.000	627.688	-144.688	-0.74493
11	673.000	627.688	45.3118	0.23329
12	1650.00	1580.11	69.8933	0.35984

0 residuals beyond 3 sigma.

Model fitting results for: 13.hours

Independent variable	coefficient	std. error	t-value	sig.level
13.econ	67.880616	130.45343	0.5203	0.6141
13.tttrips	278.485237	97.05637	2.8693	0.0167
13.otrips	951.327343	46.182425	20.5993	0.0000

R-SQ. (ADJ.) = 0.9868 SE= 186.047930 MAE= 113.012936 DurWat= 1.806
 Previously: 0.9870 177.396991 105.483001 1.825
 13 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	31096225.	3	10365408.	299.459	.0000
Error	346138.	10	34613.8		
Total	31442363.	13			

R-squared = 0.988991

R-squared (Adj. for d.f.) = 0.98679

Std. error of est. = 186.048

Durbin-Watson statistic = 1.80618

Regression results for 13.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2249.02	120.979	0.65026
2	1266.00	1297.69	-31.6932	-0.17035
3	290.000	346.366	-56.3659	-0.30296
4	48.0000	67.8806	-19.8806	-0.10686
5	838.000	346.366	491.634	2.64251
6	4133.00	4151.68	-18.6752	-0.10038
7	200.000	346.366	-146.366	-0.78671
8	236.000	346.366	-110.366	-0.59321
9	1166.00	1297.69	-131.693	-0.70785
10	483.000	624.851	-141.851	-0.76244
11	673.000	624.851	48.1489	0.25880
12	1650.00	1576.18	73.8216	0.39679
13	1220.00	1297.69	-77.6932	-0.41760

0 residuals beyond 3 sigma.

Model fitting results for: 14.hours

Independent variable	coefficient	std. error	t-value	sig.level
14.econ	68.737986	121.056395	0.5678	0.5816
14.tttrips	278.240275	92.182087	3.0184	0.0117
14.otrips	951.08238	43.270529	21.9799	0.0000

R-SQ. (ADJ.) = 0.9870 SE= 177.396991 MAE= 105.483001 Durbwat= 1.825
 Previously: 0.9870 171.398065 101.744066 1.831
 14 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	31220100.	3	10406700.	330.690	.0000
Error	346167.	11	31469.7		
Total	31566267.	14			

R-squared = 0.989034

R-squared (Adj. for d.f.) = 0.98704

Std. error of est. = 177.397

Durbin-Watson statistic = 1.82495

Regression results for 14.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2249.14	120.857	0.68128
2	1266.00	1298.06	-32.0606	-0.18073
3	290.000	346.978	-56.9783	-0.32119
4	48.0000	68.7380	-20.7380	-0.11690
5	838.000	346.978	491.022	2.76793
6	4133.00	4151.31	-18.3078	-0.10320
7	200.000	346.978	-146.978	-0.82853
8	236.000	346.978	-110.978	-0.62559
9	1166.00	1298.06	-132.061	-0.74444
10	483.000	625.219	-142.219	-0.80170
11	673.000	625.219	47.7815	0.26935
12	1450.00	1576.30	73.6991	0.41545
13	1219.00	1298.06	-78.0606	-0.44003
14	352.000	346.978	5.02174	0.02831

0 residuals beyond 3 sigma.

Model fitting results for: .15.hours

Independent variable	coefficient	std. error	t-value	sig.level
.15.econ	57.211553	114.309528	0.5005	0.6252
.15.tttrips	281.53354	88.783181	3.1710	0.0081
.15.otrips	954.375645	41.203673	23.1623	0.0000
R-SQ. (ADJ.) = 0.9870 SE= 171.398065 MAE= 101.744066 Durbwat= 1.831				
Previously: 0.9870 170.815537 109.541667 1.899				
15 observations fitted, forecast(s) computed for 0 missing val. of dep. var.				

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	31282908.	3	10427636.	354.956	.0000
Error	352528.	12	29377.3		
Total	31635436.	15			

R-squared = 0.988857

R-squared (Adj. for d.f.) = 0.986999

Std. error of est. = 171.398

Durbin-Watson statistic = 1.83059

Regression results for .15.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2247.50	122.504	0.71473
2	1266.00	1293.12	-27.1207	-0.15823
3	290.000	338.745	-48.7451	-0.28440
4	48.0000	57.2116	-9.21156	-0.05374
5	838.000	338.745	499.255	2.91284
6	4133.00	4156.25	-23.2477	-0.13564
7	200.000	338.745	-133.745	-0.80949
8	236.000	338.745	-102.745	-0.59945
9	1166.00	1293.12	-127.121	-0.74167
10	483.000	620.279	-137.279	-0.80093
11	673.000	620.279	52.7214	0.30760
12	1650.00	1574.65	75.3457	0.43959
13	1220.00	1293.12	-73.1207	-0.42661
14	352.000	338.745	13.2549	0.07733
15	263.000	338.745	-75.7451	-0.44193

0 residuals beyond 3 sigma.

Model fitting results for: .16.hours

Independent variable	coefficient	std. error	t-value	sig.level
.16.econ	71.856322	112.891058	0.6365	0.5355
.16.tttrips	276.163793	88.303765	3.1274	0.0080
.16.otrips	957.304598	40.949891	23.3775	0.0000

R-SQ. (ADJ.) = 0.9870	SE= 170.815537	MAE= 109.541667	DurbWat= 1.899	
Previously: 0.9865	172.001407	110.171266	1.999	
16 observations fitted, forecast(s) computed for 0 missing val. of dep. var.				

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	33396492.	3	11132164.	381.527	.0000
Error	379313.	13	29177.9		
Total	33775805.	16			

R-squared = 0.98877

R-squared (Adj. for d.f.) = 0.987042

Std. error of est. = 170.816

Durbin-Watson statistic = 1.89875

Regression results for .16.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2262.63	107.371	0.62858
2	1266.00	1305.32	-39.3247	-0.23022
3	290.000	348.020	-58.0201	-0.33967
4	48.0000	71.8563	-23.8563	-0.13966
5	838.000	348.020	489.980	2.86847
6	4133.00	4177.24	-44.2385	-0.25898
7	200.000	348.020	-148.020	-0.86655
8	236.000	348.020	-112.020	-0.65580
9	1166.00	1305.32	-139.325	-0.81564
10	483.000	624.184	-141.184	-0.82653
11	673.000	624.184	48.8161	0.28578
12	1650.00	1581.49	68.5115	0.40108
13	1220.00	1305.32	-85.3247	-0.49951
14	352.000	348.020	3.97989	0.02330
15	263.000	348.020	-85.0201	-0.49773

0 residuals beyond 3 sigma.

Regression results for .16.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1305.32	157.675	0.92307

0 residuals beyond 3 sigma.

Model fitting results for: 17.hours

Independent variable	coefficient	std. error	t-value	sig.level
17.econ	56.307417	112.768939	0.4993	0.6253
17.tttrips	281.865058	88.761593	3.1755	0.0067
17.otrips	954.194817	41.134568	23.1969	0.0000

R-SQ. (ADJ.) = 0.9865	SE= 172.001407	MAE= 110.171266	DurbWat= 1.999	
Previously: 0.9862	169.918564	110.059259	2.032	
17 observations fitted, forecast(s) computed for 0 missing val. of dep. var.				

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	34598166.	3	11532722.	389.823	.0000
Error	414183.	14	29584.5		

Total	35012349.	17			

R-squared = 0.98817

R-squared (Adj. for d.f.) = 0.98648

Std. error of est. = 172.001

Durbin-Watson statistic = 1.99912

Regression results for 17.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2246.56	123.438	0.71766
2	1266.00	1292.37	-26.3673	-0.15330
3	290.000	338.172	-48.1725	-0.28007
4	48.0000	56.3074	-8.30742	-0.04830
5	838.000	338.172	499.828	2.90595
6	4133.00	4154.95	-21.9517	-0.12763
7	200.000	338.172	-138.172	-0.80332
8	236.000	338.172	-102.172	-0.59402
9	1166.00	1292.37	-126.367	-0.73469
10	483.000	620.038	-137.038	-0.79672
11	673.000	620.038	52.9625	0.30792
12	1650.00	1574.23	75.7676	0.44051
13	1220.00	1292.37	-72.3673	-0.42074
14	352.000	338.172	13.8275	0.08039
15	263.000	338.172	-75.1725	-0.43705

0 residuals beyond 3 sigma.

Regression results for YDATA17.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1292.37	170.633	0.99204
17	1112.00	1292.37	-180.367	-1.04864

Model fitting results for: .18.hours

Independent variable	coefficient	std. error	t-value	sig.level
18.econ	35.1875	108.302259	0.3249	0.7497
18.tttrips	309.808333	80.599452	3.8438	0.0016
18.otrips	949.970833	40.299726	23.5726	0.0000
R-SQ. (ADJ.) = 0.9862 SE= 169.918564 MAE= 110.059259 DurWat= 2.032				
Previously: 0.9798 202.090324 140.238972 1.527				
18 observations fitted, forecast(s) computed for 0 missing val. of dep. var.				

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	35181440.	3	11727147.	406.173	.0000
Error	433085.	15	28872.3		
Total	35614525.	18			

R-squared = 0.98784

R-squared (Adj. for d.f.) = 0.986218

Std. error of est. = 169.919

Durbin-Watson statistic = 2.03168

Regression results for .18.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2244.94	125.063	0.73601
2	1266.00	1294.97	-28.9667	-0.17047
3	290.000	344.996	-54.9958	-0.32366
4	48.0000	35.1875	12.8125	0.07540
5	838.000	344.996	493.004	2.90141
6	4133.00	4144.88	-11.8792	-0.06991
7	200.000	344.996	-144.996	-0.85333
8	236.000	344.996	-108.996	-0.64146
9	1166.00	1294.97	-128.967	-0.75899
10	483.000	654.804	-171.804	-1.01110
11	673.000	654.804	18.1958	0.10709
12	1650.00	1604.73	45.2250	0.26616
13	1220.00	1294.97	-74.9667	-0.44119
14	352.000	344.996	7.00417	0.04122
15	263.000	344.996	-81.9958	-0.48256

0 residuals beyond 3 sigma.

Regression results for 18.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1294.97	168.033	0.98891
17	1112.00	1294.97	-182.967	-1.07679
18	776.000	654.804	121.196	0.71326

0 residuals beyond 3 sigma.

Model fitting results for: .19.hours

Independent variable	coefficient	std. error	t-value	sig.level
19.econ	96.686679	126.111489	0.7619	0.4572
19.tttrips	289.196303	95.448272	3.0299	0.0080
19.ctrips	932.169535	47.313304	19.7021	0.0000

R-SQ. (ADJ.) = 0.9798 SE= 202.090324 MAE= 140.238972 DurbWat= 1.527
 Previously: 0.9795 198.186004 135.845819 1.990
 19 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	35658302.	3	11886101.	291.037	.0000
Error	653448.	16	40840.5		
Total	36311750.	19			

R-squared = 0.982005 Std. error of est. = 202.09
 R-squared (Adj. for d.f.) = 0.979755 Durbin-Watson statistic = 1.52665

Regression results for .19.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2249.62	120.378	0.59566
2	1266.00	1317.45	-51.4525	-0.25460
3	290.000	385.283	-95.2830	-0.47149
4	48.0000	96.0867	-48.0867	-0.23795
5	838.000	385.283	452.717	2.24017
6	4133.00	4113.96	19.0389	0.09421
7	200.000	385.283	-185.283	-0.91683
8	236.000	385.283	-149.283	-0.73869
9	1166.00	1317.45	-151.453	-0.74943
10	483.000	674.479	-191.479	-0.94749
11	673.000	674.479	-1.47929	-0.00732
12	1650.00	1606.65	43.3512	0.21451
13	1220.00	1317.45	-97.4525	-0.48222
14	352.000	385.283	-33.2830	-0.16469
15	263.000	385.283	-122.283	-0.60509

0 residuals beyond 3 sigma.

Regression results for .19.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1317.45	145.547	0.72021
17	1112.00	1317.45	-205.453	-1.01664
18	776.000	674.479	101.521	0.50235
19	835.000	385.283	449.717	2.22533

0 residuals beyond 3 sigma.

Model fitting results for: 20.hours

Independent variable	coefficient	std. error	t-value	sig.level
20.econ	81.313899	121.387469	0.6740	0.5094
20.tttrips	294.027091	93.260569	3.1527	0.0058
20.otrips	936.341578	45.880151	20.4084	0.0000

R-SQ. (ADJ.) = 0.9795 SE= 198.186004 MAE= 135.845819 Durbwat= 1.990
Previously: 0.9797 193.099107 132.676232 2.004
20 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	35712150.	3	11904050.	303.074	.0000
Error	667721.	17	39277.7		
Total	36379871.	20			

R-squared = 0.981646

R-squared (Adj. for d.f.) = 0.979487

Std. error of est. = 198.186
Durbin-Watson statistic = 1.99019

Regression results for 20.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2248.52	121.476	0.61294
2	1266.00	1312.18	-46.1826	-0.23303
3	290.000	375.841	-85.8410	-0.43313
4	48.0000	81.8139	-33.8139	-0.17062
5	838.000	375.841	462.159	2.33195
6	4133.00	4121.21	11.7927	0.05950
7	200.000	375.841	-175.841	-0.88725
8	236.000	375.841	-139.841	-0.70560
9	1166.00	1312.18	-146.183	-0.73760
10	483.000	669.868	-186.868	-0.94289
11	673.000	669.868	3.13192	0.01580
12	1650.00	1606.21	43.7903	0.22096
13	1220.00	1312.18	-92.1826	-0.46513
14	352.000	375.841	-23.8410	-0.12030
15	263.000	375.841	-112.841	-0.56937

0 residuals beyond 3 sigma.

Regression results for 20.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1312.18	150.817	0.76099
17	1112.00	1312.18	-200.183	-1.01007
18	776.000	669.868	106.132	0.53552
19	835.000	375.841	459.159	2.31681
20	261.000	375.841	-114.841	-0.57946

Model fitting results for: .21.hours

Independent variable	coefficient	std. error	t-value	sig.level
.21.econ	89.550459	115.504611	0.7753	0.4432
.21.tttrips	284.317238	85.075252	3.3420	0.0036
.21.otrips	937.625785	44.50272	21.0690	0.0000

R-SQ. (ADJ.) = 0.9797 SE= 193.099107 MAE= 132.676232 DurbWat= 2.004
 Previously: 0.9793 190.480216 129.044597 1.963
 21 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	36074725.	3	12024908..	322.494	.0000
Error	671171.	18	37287.3		
Total	36745896.	21			

R-squared = 0.981735

R-squared (Adj. for d.f.) = 0.979705

Std. error of est. = 193.099
 Durbin-Watson statistic = 2.0039

Regression results for .21.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2249.12	120.881	0.62600
2	1266.00	1311.49	-45.4935	-0.23560
3	290.000	373.868	-83.8677	-0.43432
4	48.0000	89.5505	-41.5505	-0.21518
5	838.000	373.868	464.132	2.40360
6	4133.00	4124.37	8.62916	0.04469
7	200.000	373.868	-173.868	-0.90041
8	236.000	373.868	-137.868	-0.71397
9	1166.00	1311.49	-145.493	-0.75347
10	483.000	658.185	-175.185	-0.90723
11	673.000	658.185	14.8151	0.07672
12	1650.00	1595.81	54.1893	0.28063
13	1220.00	1311.49	-91.4935	-0.47382
14	352.000	373.868	-21.8677	-0.11325
15	263.000	373.868	-110.868	-0.57415

0 residuals beyond 3 sigma.

Regression results for .21.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1311.49	151.507	0.78460
17	1112.00	1311.49	-199.493	-1.03311
18	776.000	658.185	117.815	0.61013
19	835.000	373.868	461.132	2.38806
20	261.000	373.868	-112.868	-0.58451
21	605.000	658.185	-53.1849	-0.27543

0 residuals beyond 3 sigma.

Model fitting results for: .22.hours				
Independent variable	coefficient	std. error	t-value	sig.level
.22.econ	74.030548	111.811115	0.6621	0.5159
.22.tttrips	290.097934	83.523595	3.4732	0.0025
.22.otrips	941.898473	43.482679	21.6615	0.0000
R-SQ. (ADJ.) = 0.9793 SE= 190.480216 MAE= 129.044597 DurbWat= 1.963				
Previously: 0.9788	188.243232	120.431999		1.967
22 observations fitted, forecast(s) computed for 0 missing val. of dep. var.				

Analysis of Variance for the Full Regression					
Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	36111280.	3	12037093.	331.758	.0000
Error	689372.	19	36282.7		
Total	36800652.	22			

R-squared = 0.981267

R-squared (Adj. for d.f.) = 0.979296

Std. error of est. = 190.48
Durbin-Watson statistic = 1.96324

Regression results for .22.hours				
Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2247.93	122.075	0.64088
2	1266.00	1306.03	-40.0270	-0.21014
3	290.000	364.128	-74.1285	-0.38917
4	48.0000	74.0305	-26.0305	-0.13666
5	838.000	364.128	473.872	2.48777
6	4133.00	4131.72	1.27763	0.00671
7	200.000	364.128	-164.128	-0.86166
8	236.000	364.128	-128.128	-0.67266
9	1166.00	1306.03	-140.027	-0.73513
10	483.000	654.226	-171.226	-0.89892
11	673.000	654.226	18.7736	0.09856
12	1650.00	1596.12	53.8751	0.28284
13	1220.00	1306.03	-86.0270	-0.45163
14	352.000	364.128	-12.1285	-0.06367
15	263.000	364.128	-101.128	-0.53091

0 residuals beyond 3 sigma.

Regression results for .22.hours				
Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1306.03	156.973	0.82409
17	1112.00	1306.03	-194.027	-1.01862
18	776.000	654.226	121.774	0.63930
19	835.000	364.128	470.872	2.47202
20	261.000	364.128	-103.128	-0.54141
21	605.000	654.226	-49.2264	-0.25843
22	234.000	364.128	-130.128	-0.68316

0 residuals beyond 3 sigma.

Model fitting results for: 23.hours

Independent variable	coefficient	std. error	t-value	sig.level
23.econ	45.555718	107.02519	0.4257	0.6751
23.ttrips	256.222399	86.177474	2.9732	0.0076
23.otrips	935.862905	43.180168	21.6734	0.0000
23.edata	22.902553	33.730143	0.6790	0.5053

R-SQ. (ADJ.) = 0.9788 SE= 188.243232 MAE= 120.431999 DurbWat= 1.967
 Previously: 0.9985 35.615958 24.119577 1.971
 23 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	36135841.	4	9033960.	254.941	.0000
Error	673275.	19	35435.5		
Total	36809116.	23			

R-squared = 0.981709

R-squared (Adj. for d.f.) = 0.978821

Std. error of est. = 188.243

Durbin-Watson statistic = 1.96704

Regression results for 23.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	2370.00	2265.11	104.886	0.55718
2	1266.00	1306.35	-40.3487	-0.21434
3	290.000	347.583	-57.5832	-0.30590
4	48.0000	91.3608	-43.3608	-0.23034
5	838.000	347.583	490.417	2.60523
6	4133.00	4136.84	-3.83995	-0.02040
7	200.000	370.486	-170.486	-0.90567
8	236.000	347.583	-111.583	-0.59276
9	1166.00	1283.45	-117.446	-0.62391
10	483.000	626.708	-143.708	-0.76342
11	673.000	649.611	23.3893	0.12425
12	1650.00	1585.47	64.5264	0.34278
13	1220.00	1306.35	-86.3487	-0.45871
14	352.000	370.486	-18.4858	-0.09820
15	263.000	347.583	-84.5832	-0.44933

0 residuals beyond 3 sigma.

Regression results for 23.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
16	1463.00	1329.25	133.749	0.71051
17	1112.00	1260.54	-148.544	-0.78910
18	776.000	695.416	80.5842	0.42809
19	835.000	347.583	487.417	2.58929
20	261.000	347.583	-86.5832	-0.45995
21	605.000	718.318	-113.318	-0.60198
22	234.000	347.583	-113.583	-0.60339
23	92.0000	137.166	-45.1659	-0.23993

0 residuals beyond 3 sigma.

APPENDIX C2

COMPANY A: TOTAL DATA REGRESSION MODEL

SAS

DEP VARIABLE: NRS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	18883779.47	6294593.16	663.011	0.0001
ERROR	20	189879.02690	9493.95134		
C TOTAL	23	19073658.50			
ROOT MSE		97.43691	R-SQUARE	0.9900	
DEP MEAN		859.75	ADJ R-SQ	0.9886	
C.V.		11.33317			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > T
INTERCEP	1	6.84130305	45.04157345	0.152	0.8808
TTRP	1	299.72205619	34.8436582	8.601	0.0001
OTRP	1	703.12851166	39.43218219	17.831	0.0001
OMT	1	264.98832038	36.51620630	7.256	0.0001

COLLINEARITY DIAGNOSTICS

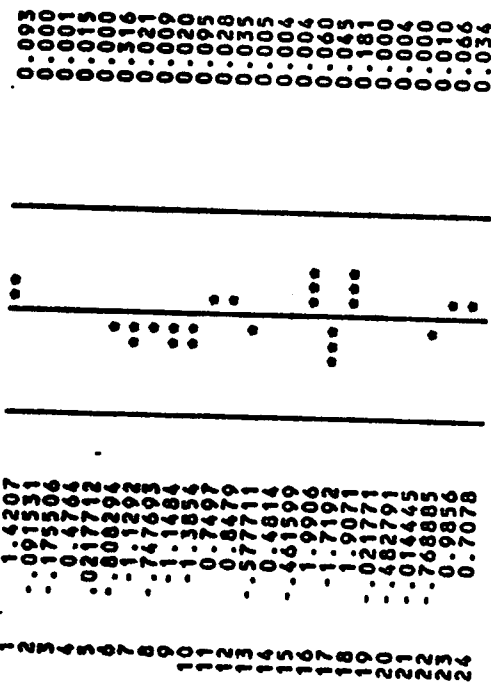
NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP TTRP	VAR PROP OTRP	VAR PROP OMT
1	2.836862	1.000000	0.0180	0.0182	0.0194	0.0192
2	0.909563	1.772264	0.0447	0.0689	0.0763	0.0478
3	0.129113	4.703918	0.2075	0.2903	0.6320	0.5555
4	0.104462	5.229565	0.7298	0.6226	0.2723	0.3776

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	2370.0	2242.8	38.3746	127.2430	89.5619
2	1266.0	1274.7	23.2797	-8.6602	94.6150
3	290.0000	306.5634	24.2351	-16.563	94.3748
4	48.0000	6.8413	45.0416	41.1587	86.4014
5	838.0000	836.5000	68.8983	1.5000	68.8983
6	4133.0	4179.0	79.1337	-45.951	56.8489
7	200.0000	306.5634	24.2351	-106.56	94.3748
8	236.0000	306.5634	24.2351	-70.563	94.3748
9	1166.0	1274.7	23.2797	-108.66	94.6150
10	483.0000	606.2854	39.6832	-123.29	88.9898
11	673.0000	606.2854	39.6832	66.7146	88.9898
12	1650.0	1574.4	39.2519	75.6178	89.1809

3

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
13	1220.0	1274.7	23.2797	-54.66	94.6150
14	323.0000	306.5634	24.2351	16.4366	94.3748
15	265.0000	306.5634	24.2351	-41.5634	94.3748
16	1463.0	1274.7	23.2797	118.2908	94.6150
17	1112.0	1274.7	23.2797	-162.66	94.6150
18	776.0000	606.2854	39.6832	169.7146	88.9898
19	835.0000	606.2854	39.6832	228.7146	88.9898
20	261.0000	306.5634	24.2351	-45.5634	94.3748
21	605.0000	606.2854	39.6832	-1.2854	88.9898
22	234.0000	306.5634	24.2351	-72.5634	94.3748
23	92.0000	6.8413	45.0416	85.1587	86.4014
24	68.0000	6.8413	45.0416	61.1587	86.4014

OBS	STUDENT RESIDUAL	COOK'S D
1	1.4207	0.093
2	1.0531	0.000
3	1.7506	0.000
4	0.4764	0.001
5	0.21712	0.015
6	0.08294	0.000
7	1.1293	0.0316
8	1.74693	0.021
9	1.1484	0.009
10	1.1854	0.009
11	0.7497	0.095
12	0.8479	0.028
13	0.57711	0.035
14	0.4814	0.005
15	0.61599	0.004
16	1.9906	0.000
17	1.7192	0.000
18	1.9071	0.043
19	0.21771	0.181
20	0.482791	0.000
21	0.01445	0.004
22	0.76885	0.000
23	0.9856	0.010
24	0.7078	0.046



SUM OF RESIDUALS -8.88178E-14
 SUM OF SQUARED RESIDUALS 189879
 PREDICTED RESID SS (PRESS) 257325.4

APPENDIX D1

COMPANY B: AS-OCCURRED REGRESSION ANALYSES

Model fitting results for: 5.hours

Independent variable	coefficient	std. error	t-value	sig.level
5.aprocs	4.046512	0.848439	4.7694	0.0413
5.cprocs	5.75	0.59308	9.6951	0.0105
5.progs	21.313953	1.291797	16.4995	0.0037

R-SQ. (ADJ.) = 0.9991 SS= 2.372321 MAE= 1.274419 DurbWat= 2.160
Previously: 0.9917 6.686343 4.836476 2.045
5 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	24879.7	3	8293.25	1473.59	.0007
Error	11.2558	2	5.62791		
Total	24891.0	5			

R-squared = 0.999548

R-squared (Adj. for d.f.) = 0.999096

Std. error of est. = 2.37232
Durbin-Watson statistic = 2.16008

Regression results for 5.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	12.0000	13.8430	-1.84302	-0.77689
2	37.0000	35.1570	1.84302	0.77689
3	143.000	142.756	0.24419	0.10293
4	25.0000	27.0640	-2.06395	-0.87001
5	48.0000	48.3779	-0.37791	-0.15930

0 residuals beyond 3 sigma.

Model fitting results for: 6.hours

Independent variable	coefficient	std. error	t-value	sig.level
6.cprocs	10.182247	0.937011	10.8667	0.0004
6.intrvms	10.170463	1.357857	7.4901	0.0017

R-SQ. (ADJ.) = 0.9917 SE= 6.686343 MAE= 4.836476 DurbWat= 2.045
 Previously: 0.9923 5.985055 4.231717 2.232
 6 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	26828.2	2	13414.1	300.043	.0000
Error	178.829	4	44.7072		
Total	27007.0	6			

R-squared = 0.993378

R-squared (Adj. for d.f.) = 0.991723

Std. error of est. = 6.68634
 Durbin-Watson statistic = 2.04521

Regression results for 6.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	12.0000	20.3527	-8.35271	-1.24922
2	37.0000	30.5232	6.47683	0.96866
3	143.000	142.504	0.49568	0.07413
4	25.0000	30.5232	-5.52317	-0.82604
5	48.0000	50.8641	-2.86410	-0.42835
6	46.0000	40.6936	5.30636	0.79361

0 residuals beyond 3 sigma.

Model fitting results for: 7.hours

Independent variable	coefficient	std. error	t-value	sig.level
7.cprocs	10.172531	0.83139	12.2356	0.0001
7.intrvms	10.170261	1.215438	8.3676	0.0004

R-SQ. (ADJ.) = 0.9923 SE= 5.985055 MAE= 4.231717 DurWat= 2.232
 previously: 0.9251 22.026262 13.747593 2.522
 7 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	27727.9	2	13863.9	387.035	.0000
Error	179.104	5	35.8209		
Total	27907.0	7			

R-squared = 0.993582

R-squared (Adj. for d.f.) = 0.992299

Std. error of est. = 5.98506
 Durbin-Watson statistic = 2.23212

Regression results for 7.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	12.0000	20.3428	-8.34279	-1.39394
2	37.0000	30.5131	6.48695	1.08306
3	143.000	142.406	0.59364	0.09919
4	25.0000	30.5131	-5.51305	-0.92114
5	48.0000	50.8536	-2.85358	-0.47678
6	46.0000	40.6833	5.31669	0.88833
7	30.0000	30.5133	-0.51332	-0.08610

0 residuals beyond 3 sigma.

Model fitting results for: 8.hours

Independent variable	coefficient	std. error	t-value	sig.level
8.cprocs	10.012444	3.217141	3.1122	0.0208
8.progs	12.459259	4.238956	2.9392	0.0260

R-SQ. (ADJ.) = 0.9251 SE= 22.026262 MAE= 13.747593 DurWat= 2.522
Previously: 0.6908 27.693118 18.491503 1.718
8 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	42420.1	2	21210.0	43.7179	.0003
Error	2910.94	6	485.156		
Total	45331.0	8			

R-squared = 0.935785

R-squared (Adj. for d.f.) = 0.925082

Std. error of est. = 22.0263
Durbin-Watson statistic = 2.52216

Regression results for 8.hours

Observation Number	Observed Values	Fitted Values	Residuals	Standardized Residuals
1	12.0000	10.0124	1.98756	0.09024
2	37.0000	22.4717	14.5283	0.65959
3	143.000	149.961	-6.96148	-0.31603
4	25.0000	22.4717	2.52830	0.11479
5	48.0000	34.9310	13.0690	0.59334
6	46.0000	47.3902	-1.39022	-0.06312
7	30.0000	69.8619	-39.8619	-1.80975
8	132.000	102.346	29.6539	1.34630

0 residuals beyond 3 sigma.

APPENDIX D2

COMPANY B: TOTAL DATA REGRESSION MODEL

SAS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MRS

STEP 1 VARIABLE PROGS ENTERED

R SQUARE = 0.84446093 C(P) = 78.17729323	
DF	SUM OF SQUARES
REGRESSION	41525.38271603
ERROR	7649.61728395
TOTAL	49175.00000000
	MEAN SQUARE
	41525.38271605
	956.20216049
	F
	43.43
	PROB>F
	0.0002
PROGS	22.64197531
	STD ERROR
	3.43583541
	TYPE II SS
	41525.38271605
	F
	43.43
	PROB>F
	0.0002
BOUNDS ON CONDITION NUMBER:	1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE CPROCS ENTERED

R SQUARE = 0.93725060 C(P) = 20.35860521	
DF	SUM OF SQUARES
REGRESSION	46089.29832884
ERROR	3083.70160116
TOTAL	49175.00000000
	MEAN SQUARE
	23044.64919942
	440.81451445
	F
	52.28
	PROB>F
	0.0001
CPROCS	9.47016012
	STD ERROR
	2.94317753
	TYPE II SS
	4563.91568279
	F
	10.33
	PROB>F
	0.0147
BOUNDS ON CONDITION NUMBER:	2.475983, 9.90393

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE APROCS ENTERED

R SQUARE = 0.95620790 C(P) = 20.97862491	
DF	SUM OF SQUARES
REGRESSION	47021.52345051
ERROR	2133.47654949
TOTAL	49175.00000000
	MEAN SQUARE
	15673.84115017
	43.67
	PROB>F
	0.0002
APROCS	7.76891905
	STD ERROR
	4.82052855
	TYPE II SS
	932.22505167
	F
	2.60
	PROB>F
	0.1582
CPROCS	10.51053938
	STD ERROR
	2.73305647
	TYPE II SS
	5308.13175239
	F
	14.79
	PROB>F
	0.0085
BOUNDS ON CONDITION NUMBER:	3.916031, 25.24767

SAS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE HRS

STEP 3

PROCS REPLACED BY INTRVUS

R SQUARE = 0.9591097
C(P) = 19.38903208

	OF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	47166.28188247	15722.42729416	46.91	0.0001
ERROR	6	2010.71811733	335.11968626		
TOTAL	9	49175.00000000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
APROCS	11.03340649	3.95326391	2610.40301537	7.79	0.0315
CPROCS	11.60692514	2.28241798	8666.50410469	25.86	0.0023
INTRVUS	7.88978298	3.23730615	1990.50150360	5.94	0.0507

BOUNDS ON CONDITION NUMBER: 2.220373, 16.59437

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

DEP VARIABLE: HRS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	47164.28188	15721.42729	46.913	0.0001
ERROR	6	2010.71812	335.11968626		
U TOTAL	9	49175.00000			
ROOT MSE		18.30627	R-SQUARE	0.9591	
DEP MEAN		59.44444	ADJ R-SQ	0.9387	
C.V.		30.7956			

NOTE: NO INTERCEPT TERM IS USED. R-SQUARE IS REDEFINED.

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > T
APROCS	1	11.03340649	3.95326391	2.791	0.0315
CPROCS	1	11.60692514	2.28241798	5.085	0.0023
INTRVMS	1	7.88978298	3.23730615	2.437	0.0507

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP APROCS	VAR PROP CPROCS	VAR PROP INTRVMS
1	2.077971	1.000000	0.0929	0.0860	0.0842
2	0.634111	1.810244	0.8236	0.1982	0.0338
3	0.287918	2.686488	0.0835	0.7158	0.8820
OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL
1	37.0000	49.4533	7.2642	-12.453	16.8033
2	30.0000	42.1370	4.1128	-12.137	17.8383
3	46.0000	35.2763	8.4680	10.7237	16.2300
4	48.0000	43.1661	11.6530	4.8339	14.1183
5	62.0000	65.2329	11.1440	-3.2320	14.5235
6	25.0000	27.3865	5.3461	-2.3865	17.5083
7	143.0000	147.6284	17.8222	-4.6284	4.1818
8	12.0000	41.5635	6.9641	-29.564	16.9299
9	132.0000	106.3409	14.4664	25.6591	11.2180

OBS	STUDENT RESIDUAL	-2	-1	0	1	2	COOK'S D
1	-.741122			*			0.034
2	-.680393			*			0.008
3	0.6607				*		0.040
4	0.3424						0.027
5	-.222596						0.010
6	-.136307						0.001
7	-1.1068			**			7.417
8	-1.7462			***			0.172
9	2.2873				***		2.900

SUM OF RESIDUALS -23.1848
 SUM OF SQUARED RESIDUALS 2010.718
 PREDICTED RESID SS (PRESS) 14398.02

VITA

Denise Ford Jackson was born in Vicksburg, Mississippi, on June 9, 1958 to Zack and Ardell Ford. She attended the public schools in that city and graduated from Vicksburg High School in June 1976. The following September she attended the Georgia Institute of Technology in Atlanta, and, in June 1980, she received a Bachelor of Industrial Engineering degree. She worked as a Systems Engineer from July 1980 to September 1984 for Union Carbide/Martin Marietta in Oak Ridge, Tennessee. She received a Master of Science degree in Industrial Engineering from the University of Tennessee at Knoxville in August 1983. She began work on a Doctoral degree at the University of Tennessee in September 1984 and also became an Instructor in the Industrial Engineering department.

She is married to Andrew J. Jackson of Knoxville, Tennessee.