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A DYNAMIC APPROACH TO THE DETERMINATION OF SHIPPING STANDARDS

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CHAPTER I

TRADITIONAL PERFORMANCE STANDARDS: EVOLUTION AND PROBLEMS

Performance standards are cited in the production and operations management literature as one of the most widely used tools for the planning, organizing, and controlling of manufacturing functions. The proper use of performance standards aids in the planning of manpower needs, the allocation of workload, the evaluation of performance, and in the control of labor costs.

An extensive literature search reveals that writers of both periodic and textual material have not treated in any depth the order picking and accumulation activity as a functional area nor as a potential locus for the application of performance standards.

Purpose. The purpose of this dissertation is to seek methods for the establishment of performance standards for indirect labor tasks. The methods will be investigated and evaluated in the context of a specific function (order picking and accumulation) in an existing firm. Indirect labor tasks as used in this context are characterized primarily as those whose elements do not occur in a predictable sequence. Under these conditions companies have either not set specific standards or they have modified the traditional work study methods to adopt them to this less routine environment.

This dissertation is designed to:

1. Determine appropriate methods for establishing performance standards for non-repetitive tasks

2. Apply these methods to the order picking and accumulation function in an existing environment

3. Demonstrate the relative efficiency of the methods applied as contrasted with a traditional approach

Overview of methodology. This study first reviews the literature on work methods and performance standards to determine techniques that have been applied, their limitations, and the conditions necessary for their application.

The empirical portion of the dissertation examines the order picking and accumulation function in an existing manufacturing company. The object is to determine appropriate criteria for performance standards in that application and the environmental conditions in which the standards are to be used. Following the job and environmental analysis, performance standards are developed by applying techniques reported in the literature and developed for the specific environment. These are evaluated on the criteria developed in the literature and the job analysis.

The general hypothesis is that effective, efficient performance standards can be established for the order picking and accumulation function.

Historical considerations. The formalized study and quantification of performance standards began with the advent of the "Scientific Management" era. One of the more important societies that proliferated with the spread of the Scientific Management movement was the "Efficiency Society." While short-lived, it was significant because its membership was comprised of a mixture of industrial and business managers as well as management theorists, educators, economists and writers whose cross-fertilization of ideas embodied much of what has since come to be known as "Production and Operations Management." Its name was unfortunate since the word "efficiency" had begun to have a rather abrasive impact upon the general public. Charles Buxton Going, Managing Editor of Engineer Magazine, summarized the purposes and objectives of the society as follows:

> The essence of the Efficiency Movement is insistence upon a determination of standards of achievement--equitable and reasonable standards by which the ratio of useful result secured to the effort expended, or the expense incurred in any given case, may be compared with the ratio that should exist in a normal utilization of the agencies at hand. Efficiency does not demand nor even encourage strenuousness. It does not impose nor even countenance parsimony. It merely demands equivalence, equivalence between power supplied and work performed; equivalence between natural resources utilized and products obtained; equivalence between vital opportunity and individual or national health; equivalence between attainable degrees of security and the actual proportion of casualties; equivalence between production capacity and finished product.[1]

The standards of achievement cited above as fundamental to the Efficiency Movement depended upon standardization. In one of the earliest texts dealing specifically with industrial management, Davis states, ". . . as a rule, the standardization of conditions must precede the standardization of functions . . ."[2]

Barnes further suggested that the most effective functions were a synthesis of the most effective motions. The motions he suggested be standardized related to the application of the following motion principles:

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[1]Charles Buxton Going, "The Efficiency Movement: An Outline," Proceedings of the Efficiency Society, Inc., p. 13, 1912.

[2]Ralph C. Davis, Industrial Organization and Management (New York: Harper and Brothers, 1940).

1. The most effective method usually is a synthesis of a minimum number of unit motions
2. Hand motions may be classified in accordance with the kind and number of body elements involved. They should be broken down into the lowest classification with which the work can be done properly
3. There is a normal work area for each classification of hand motions. Materials and tools should be so located that motions are held to the lowest classification possible
4. As far as possible, all tools should be placed where they can be grasped in the least time and with the least effort
5. The motions of the arms should be simultaneous, symmetrical, and opposed in direction
6. Rhythm in work tends to improve coordination and reduce fatigue. It is a function of time, rather than of distance
7. The hand is an inefficient holding device; hence, whenever possible, it should be freed for more productive use by the provision of a mechanical holding device
8. Hesitation in making motions should be analyzed for it may indicate faulty relationships between motions, physical conditions, work habits, etc.[3]

In summary, early work in the determination of performance standards was centered upon those functions that were predictable both in movement content and the sequential relationship of movement. The motions were analyzed and standardized, then measured. The first universally accepted method for measurement was time study which was performed with a stopwatch.

Time study. Current works which deal with the practice of time study, as distinct from motion study, reflect the same insistence upon the standardized and predictable sequence of operations that characterized the early motion study literature.

Mundel gave five distinct steps for defining the unit of measurement in the setting of a performance standard by time study:

1. This need be done only once for all studies in the plant
2. Recording the standard practice
3. Observing the time taken by a particular operator
4. Rating or relating performance to the standard

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[3]Ralph M. Barnes, Motion and Time Study (New York: John Wiley, 1937), p. 110.

5. Application of allowances[4]

With reference to the standard practice, he continued:

> A standard time is defined as a specified proportion of time necessary to accomplish a unit of work, using a given method, under given conditions of work, by a worker possessing a specified amount of skill on the job and a specified aptitude for the job, when working at a pace that will utilize, within a given period of time the maximum physical exertion such a worker could expend on such a job without harmful physical effects. It is further indicated that this general definition listed the variables in the situation subjected to time study measurement.
>
> Any time study predicts either the previous existence of, or the creation of, a written standard practice.
>
> Before any other phases of the measurements for standard time are made, the method and conditions should be recorded in sufficient detail so that the job and the conditions surrounding it, may be reproduced or examined at any time in the future exactly as they were at the time of study. This is the guiding principle for preparing an adequate written standard practice.[5]

In practice, it is usually desirable to break the task into steps referred to as time study elements. These elements are the finite portions of the job that are studied separately. Because they are studied separately, care must be used in the selection and definition of these elements. Mundel suggests the following criteria be observed for selection:

> 1. Easily detected and definite end point. This will facilitate timing because the well defined end point is easier to note accurately. The most desirable type of end point is one which permits some means of anticipating its occurrence so that the time study man may prepare to read his watch at the correct instant. For example, it is easier to determine the instant a lathe chuck key is laid upon a bench than the instant the worker is finished tightening the chuck preparatory to removing the key. However, a compromise is sometimes necessary when this requirement conflicts with one of the others which follow
>
> 2. As small as is convenient to time. When stopwatches are used, the smallest practical unit is about 0.04 minute, or 3 seconds. Even this, however, requires skill on the part of the time study man. If motion picture films are taken and later analyzed or if time study

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[4]Marvin E. Mundel, Motion and Time Study (New York: Prentice-Hall, 1953), p. 261.

[5]Ibid.

machines involving constantly moving paper tapes are used, a smaller unit is possible. However, this is not yet common practice and in many cases is not necessary. Unless detailed basic times are to be developed or unless the job naturally breaks up into many small elements, fine measuring techniques are not used nor are they necessary

3. As unified as possible. The element should consist of a well unified group of motions such as reach for, take hold of an object, move it, and place it, rather than part of a series of movements with one object and part of another series with another object. The worker usually tends to perform such activities as a pattern, rather than as a series of acts; hence, the motions should be timed as a group and should not be divided at an odd place. Also, an operator may possess different amounts of the different skills required by the various steps of the job; thus, his performance on each step is best judged when separated. In addition, breaking the job down into elements involving only manipulative ability, visual perceptions, strength, and so forth, facilitates the subsequent job of rating[6]

4. Hand time should be separated from machine time. Hand time is subject to the control of the operator; machine time, with automatic feeds or fixed speeds, is not. Even where hand feeds are used, the proper time for the machine work is determinable with a highly mechanistic form of experimentation.[7] Machine time also permits a high degree of standardization and cross-checking from study to study. Hand time is much more variable and harder to determine precisely. Hence, these two types of times should invariably be separated

5. Constant elements should be separated from variable elements. The act of starting a machine is usually independent of the piece being worked on. The act of setting aside a given type of material box is often independent of the nature of the pieces in it, and is usually independent of the operation performed. Elements of this type should be kept separate from those involved in the actual handling of the piece, which will probably vary with the size, shape and weight of the individual piece, its location, orientation, and how easily it may be handled

6. Regular and irregular elements should be separated. Elements that do not occur in every cycle should be kept separate to facilitate proper prorating. Often, considerable observation is required to find them, but they are a valid part of the job[8]

The above criteria are recorded in detail because, having examined the shipping environment and documented its characteristics, each

[6]Rating is the process of determining how fast the person studied is working as related to a concept of a normal work pace. An analyst observes this pace, compares it with other paces and learns to judge pace level as a percent of normal.

[7]H. Rossmore, "A New Tool for the Time Study Engineer," Modern Management, Vol. IX, No. 1 (January 1949), p. 14.

[8]Mundel, Motion and Time Study, p. 276.

point will be examined to determine the feasibility of utilizing time study methods in the study at hand.

The entire process of analyzing a task in terms of the elements involved leads to the first improvement upon the traditional time study approach, i.e., the evolution of Standard Data.

Standard data. Historically, as time studies were taken, it became apparent that the descriptions of the elements were similar. For example, studies of machining operations often contained an element described as "position piece in chuck." Further observation revealed that time values, repeatedly in studies, were approximately the same; hence, it became apparent that under certain conditions the results of prior studies might be used rather than restudy the element in question. As more and more elemental data were collected, it became possible to construct entire jobs from previously determined elemental data. In addition to eliminating duplicate studies, Nadler lists the following predictive capabilities of Standard Data.

> 1. Less time is required for direct observational time study. Time studies will still be needed for establishing standard times on completely different classes of work, as well as to check, maintain, and extend present Standard Data
> 2. Production and office flow lines can be balanced and workloads established before output is required
> 3. Costs, schedules, and delivery data can be predicted before any work is done on a product or to produce a service
> 4. Greater consistency is obtained in establishing standard times. Standard Data tend to eliminate some of the random errors of the time study and other data gathering procedures
> 5. Greater economy is achieved in setting standard times. Fewer man-hours are required, and more activities can be pursued in developing better models of work measurements[9]

The conditions required for successful application of Standard Data are also commented upon by Nadler:

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[9]Gerald Nadler, Work Design (Homewood, Illinois: Richard D. Irwin, Inc. 1963), p. 464.

Assumption #1. Many research projects show that an individual, accurate, independent, and universal time value for a particular therblig[10] is difficult to establish, and that the time value for one therblig is highly dependent on and interrelated with other therblig times.[11] This assumption means that a standard time must be established for each basic motion with exactly the same procedures used in time study.[12]

The same limitations and environmental constraints that bound time study also restrict Standard Data. Moreover, from early programs of Standard Data came the concept of a more universal set of time values which relate to the body instead of the work place.

Predetermined time systems. As companies developed their own Standard Data, consultants and other professionals began to compare these. Again, similarities raised the possibility that a set of values not bounded by a given organizational environment might be calculated. This evolution (from common times for work elements to common times for body motions) served to greatly expand the usefulness of time study analyses and research. In-depth studies of times for body motions could

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[10]A therblig (Gilbreth spelled backwards) is a breakdown of all activities of the hands into 17 separate identifiable categories. See Edna Yost, Frank and Lillian Gilbreth, Partners for Life (New Brunswick, New Jersey: Rutgers University Press, 1949).

[11]Some references include H. Schmidtke and F. Stier, "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," Journal of Industrial Engineering, Vol. 12, No. 3, May-June 1961, pp. 182-204; G. Nadler and J. W. Wilkes, "Studies in Relationship of Therbligs," Advanced Management, Vol. 18, No. 2, February 1953, pp. 20-22; W. D. Seymour, "Experiments on the Acquisition of Industrial Skills (Part 4)," Occupational Psychology, Vol. 33, No. 1, January 1959, pp. 18-35; E. A. Fleishman, "The Prediction of Total Task Performance from Prior Practice on Task Components," Human Factors, Vol. 7, No. 1, February 1965, pp. 18-28; R. O. Freedle, A. Zarala, and E. A. Fleishman, "Studies of Component-Total Task Relations," Human Factors, Vol. 10, No. 3, June 1968, pp. 283-296; R. Nanda, "The Additivity of Elemental Times," Journal of Industrial Engineering, Vol. 19, No. 5, May 1968, pp. 235-242.

[12]Nadler, p. 465.

be used universally on comparable motions, whereas time studies of specific work elements were restricted to comparable work categories or tasks.

The expanded usefulness of the data seemed to justify more sophisticated techniques. Accordingly, time values for basic body motions were determined primarily by micro-motion analyses, using chronocyclegraphic and stroboscopic measurements rather than by stopwatch studies.

Frank and Lillian Gilbreth called the analysis of body movements made with motion pictures and a timing device "micro-motion" study. In most cases, the spring drive mechanism of the camera is sufficiently consistent to use a frame count as a timing device, although some variability is present. The most frequently used timing devices include a synchronous motor drive attached to the camera, and a microchronometer which is placed in the picture to be taken. The microchronometer's large hand rotates at 20 r.p.m. and the small hand at 2 r.p.m.; thus, each small division is 1/2,000 minute. This affords an accurate timing of each movement through examination of the exposed film. The start and stop of each movement are seen with the start and stop time on each frame.

The use of stroboscopic lights, in conjunction with the camera, produces a picture showing the position of a person during various parts of an operation. Such pictures are usable only as a general presentation of work methods and function, i.e., not to time movements but rather to highlight wasted motions.

The chronocyclegraph, on the other hand, was devised to study the motion paths of the hands. It uses a photograph of the work place with the motion paths superimposed. Although the paths are shown in two dimensions, the photograph is an effective device for portraying the relative velocities of body members. The chronocyclegraph was, and is, used mainly on highly repetitive operations which require rapid and skilled movement--such as sewing garments, clerical work, and many assembly jobs.

Advances in technology led to rapid growth in Predetermined Time Systems. The systems that evolved had the same objective, i.e., consistent time standards established from motion analysis. All of the systems presupposed that movements were sequentially definable and predictable.

Predetermined Time Systems may be classified into three basic groups. These are:

1. Acceleration-Deceleration Systems, whereby recognition is given to the principle that body motions, at their start and stop, move at varying speeds. Time values for body motions using this approach tend to average 40 percent of total time for acceleration, 20 percent for constant speed and 20 percent for deceleration

2. Average Motion Systems, wherein recognition is given to the typical or average motion difficulties that occur in manual motion and operation

3. Additive Systems, wherein basic time values are used plus additions for motion difficulties, i.e., for factors of muscular control required by the motion difficulties. Additions are made for the specific motion difficulties as encountered, with additives ranging from 10 to 50 percent

<u>Evolution of the Predetermined Time Systems</u>. The first practical

Predetermined Time System was developed by A. B. Segur.[13] Research began in 1919, assisted and stimulated by the ideas and recommendations of the Gilbreths.[14] Known as MTA, for 'Motion Time Analysis," Segur's time values are the most detailed of the acceleration-deceleration systems. Among the many outgrowths from MTA were other acceleration-deceleration systems such as Walter Holmes' "Applied Time Study."[15]

Acceleration-deceleration systems are not widely used for standards setting, although technically they provide one of the best means for detailed methods analyses and standards setting. However, Segur's work aroused a great deal of interest and, directly or indirectly, strongly influenced subsequent systems using average motions.

At General Electric, Engstrom[16] developed a system from studies of punch press and stamping operations that became known as the Engstrom Tables for "place" and "get." The Engstrom Tables were widely

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[13]A detailed description of this system can be found in R. M. Barnes and Norma Englert, Engineering and Management Literature (University of Iowa, 1944) and the John Crerar Library, Bibliography of Time and Motion Study (96 E. Randolph St., Chicago, Illinois, 1942). See also W. P. Kuhne, "Studien zur optimalen Kraftreaktion an Maschinenbedienungselementen" (Studies on the Optimum Force Exerted on Machine Controls), Industrielle Psychotechnik, Vol. 3 (June, 1926), pp. 167-172.

[14]F. B. Gilbreth, Bricklaying System (Chicago: Myron C. Clark Publishing Company, 1909). See also F. B. Gilbreth, Motion Study (New York: D. VanNostrand Company, 1911); F. B. and L. M. Gilbreth, Applied Motion Study (New York: Sturgis and Walton Company, 1917); F. B. and L. M. Gilbreth, Fatigue Study (New York: Macmillan Company, 1919); F. B. and L. M. Gilbreth, Motion Study for the Handicapped (London: George Routledge and Sons, Ltd., 1920); L. M. Gilbreth, The Psychology of Management (New York: Sturgis and Walton Company, 1914).

[15]W. G. Holmes, Applied Time and Motion Study (New York: Ronald Press Incorporated, 1938).

[16]H. Engstrom, "Development and Use of Standard Data for Setting Time Standards," Industrial Management Society Proceedings of National Time and Motion Study Clinic (1941), pp. 33-37.

published and strongly influenced additional research at General Electric and elsewhere. Upon Engstrom's earlier work, the Minneapolis-Honeywell Regulation company developed the M-H System, and General Motors the Work Time Measurement time values.[17] At about the same time, Barnes, at the University of Iowa, developed a large number of time values for body motions from laboratory and plant studies.[18]

Captain Olsen, of the Springfield Armory, developed a set of basic time values during Work War II which were used by the Armory engineers to set incentive standards.[19] The motivation for the development of these basic time values appears to have been an old government regulation going back to Scientific Management Era[20] which prohibited the use of stopwatches to set standards for United States Government employees.

In the early thirties, the Philco Corporation sponsored a study series of selected factory operations as a direct result of union resistance to stopwatch time studies. Philco engineers (Quick, Shea and Koehler) developed these into a system originally called Motion Time Standards. These engineers, along with others working for the Radio Corporation of America, did additional research and the system became

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[17] C. Sellie, Standards International, Inc., monograph 5 (Chicago: 1974).

[18] R. M. Barnes, "An Investigation of Some Hand Motions Used in Factory Work," Iowa Studies in Engineering, Vol. 6 (February 1936). See also R. M. Barnes and J. M. MacKenzie, "Motion Study Research: A Study of Positioning Small Parts," Factory Management and Maintenance Vol. 98, No. 3 (March 1940), pp. 63-66; R. M. Barnes and T. D. Speidel, "Motion and Time Study in Dental Education," Journal of Dental Education, (May 1942).

[19] Society of Industrial Engineers, Bibliography of Time Study Engineering (New York: H. H. Wilson Company, 1943), pp. 40-42.

[20] W. A. Gomberg, A Trade Union Analysis of Time Study (Chicago: Science Research Associates, 1948) pp. 10-14.

known as Work Factor.[21]

In the early forties, the Westinghouse Electric Corporation sponsored a series of studies of sensitive drill press work. These were developed by Maynard, Stegmerten and Schwab of the Methods Engineering Council. This data was called Methods Time Measurement (MTM). In recent years, Master Standard Data, Unified Data, and Modapts have been developed in the search for simpler application. Average Motion Systems are the most widely published and publicized of the three basic systems.[22]

Segur's tables and techniques for start and stop times also influenced the additive Systems. The Elemental Time Standards System was initiated at the Western Electric Company in the early 1920's and has since been perfected to a level at which it has gained extensive application in a large number of the firm's plants.[23]

At the General Electric Company, the Engstrom Tables were further developed and refined to allow for extra controls. This system was called Motion Time Survey. Based upon these data, a series of conveniently arranged tables for motion combinations were then developed by Geppinger, of the same organization, to become the Dimensional Motion Time System. These basic values called MTS or DMT are used for time and motion study at General Electric and a variety of other companies.[24]

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[21]"Applying Motion Study Principles: R.C.A. Manufacturing Company," Factory Management and Maintenance, Vol. 100, No. 8 (August 1942) pp. 128-129.

[22]H. B. Maynard, "Methods Engineering Installation," Modern Machine Shop, Vol. 9 (July 1936), p. 62.

[23]Bibliography of Time Study Engineering, p. 31.

[24]L. P. Persing, "Motion Study in the General Electric Company," Human Factors, Vol. 7 (April 1933) pp. 123-131.

Basic Motion Times (BMT) was developed by Woods and Gordon; Simplified Motion Systems (SMS) by Dill.[25] Both systems are designed to simplify the compensation for stops and starts caused by motion difficulties. BMT was strongly influenced by the RCA and Westinghouse systems. SMS was similarly influenced by RCA and Minneapolis-Honeywell techniques.

From an academic viewpoint, each system appears to possess strengths and weaknesses that must be weighed against existing environmental conditions. From a pragmatic view, applications tend to indicate that Acceleration-Deceleration systems tend to be used on production run work. Additive Systems find favor in the job shop operations. Average Systems are the most popular and find application in both manufacturing settings. None has been successfully applied to the general shipping function or specifically to order picking and accumulation.

Definition of shipping. The term "shipping" broadly designates the movement of goods to a customer. Sometimes shipping activities are organizationally combined with those of receiving thereby providing some common supervision and facilities to the receipt of goods from suppliers and the movement of goods to a customer. Hence, the term "shipping department" is not nearly as definitive as most other organizational units. For example, when the Production and Inventory Control Department is mentioned, one infers certain jobs, techniques, and organizational relationships. The shipping department, however, may be handling anything from the movement of ore to finished products. The tools used in the shipping function cover the entire field of material handling equipment,

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[25] C. Sellie, monograph 5.

packaging materials, and fastening hardware.

Order picking and accumulation. The focus of this study is upon those industries that manufacture and inventory. The manufactured goods are placed in temporary storage, generally with like items, and the term "order picking and accumulation" applies to the activity that is initiated by the receipt of an order. When the order arrives in the shipping department, someone is assigned to fill it. This means reading the line items; associating the goods specified with positions in the warehouse; moving to those positions; accumulating the number of units specified; and finally moving, and/or causing to be moved, the completed order to a dock for loading. This activity sequence is typical for movement to the purchaser of consumer goods and a large portion of industrial goods. It is, therefore, the classic kind of activity sequence engaged in by many shipping departments.

Although the order picking and accumulation function is common to many manufacturing facilities, a review of periodic literature anthologies, from 1954 to 1975, indicates that no applications of incentive systems to that function have been reported. During the same period, other functions that are commonly designated "indirect Labor" have undergone a number of work measurement investigations. A search of nonperiodic published sources yielded the following single reference to incentive payment for cost reduction and/or goal attainment:

> Plans [incentive] based upon reduction of personnel and payment for maintaining schedules. Possible applications: storeroom, routine maintenance and shipping.[26]

This source suggests a subjective method for sharing the monetary

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[26]G. B. Carson, Production Handbook, 3rd. ed. (New York: The Ronald Press Company, 1967), p. 89.

rewards of cost reduction and/or increased effectiveness. No systematic methodology is discussed. Further, the shipping function is referred to only within the context of other indirect labor areas, not the single focus of the reference.

The lack of applications of performance standards to order picking and accumulation can be explained in part by examining the conditions that were cited earlier in this chapter as being basic to the historic work measurement techniques. Mundel, as quoted on page 5, laid exacting criteria for those conditions that must exist prior to measurements being taken for standard times. His guiding principle was that all methods and conditions surrounding the job be recorded in such detail that they may be reproduced exactly as they were at the time of the study at any time in the future. Unfortunately, the warehouse environment seldom fits this criteria. The dynamics of the market alone preclude the satisfaction of replicability as a condition that must exist to use time study techniques. New lines are added; old ones cut back or dropped. As a result, product locations are varied. Indeed, all or parts of the layout may be rapidly rearranged. If time study techniques were used in the warehouse environment, any of the changes mentioned above would require that the performance standards be restudied.

Limitations. With reference to the determination of time study elements, Mundel's criteria are again quoted as a springboard for the writer's comments.

> 1. Easily detected and definite end point. . . . The most desirable type of end point is one which permits some means of anticipating its occurrence.

This consideration would pose some difficulty in the time study of an order picker. For example, in an element such as "move to next item location," the time study person--to be able to anticipate the ending of that element--would have to know the next item to be picked and its location. The same difficulty arises for the next element which presumably might be "remove goods from storage." In order to anticipate the end of this element, the time study person would have to know how many units were ordered.

2. As small as is convenient to time. . . .

This criterion poses no problem since most logical elements will be longer in the study of the order picker than in the similar study of an assembler or machine operator.

> 3. As unified as possible. The element should consist of a well unified group of motions such as, reach for, take hold of an object, move it, and place it, rather than part of a series of movements with one object and part of a series with another object, . . . In addition, breaking the job down into elements involving only manipulative ability, visual perception, strength, and so forth, facilitates the subsequent job of rating.

The order picking job does not include a well-unified series of motions. It can consist of disparate movements such as walking, lifting, stacking, writing, manipulation of banding tools and labeling. The problem is further compounded by the fact that these physical movements are interspersed with certain mental processes, primarily cognition and association. The order picker must translate the symbolic logic contained on the order into a stock item and then associate that mental image with a location in the warehouse.

> 4. Hand time should be separated from machine time. . . . Hand time is much more variable and harder to determine precisely.

The activity of an order picker contains no machine time that occurs in a predictable sequence.

> 5. Constant elements should be separated from variable elements. . . . Elements of this type [constant] should be kept separate

> from those involved in the actual handling of the piece which will probably vary with the size, shape, and weight of the individual piece, its location, orientation, and how easily it might be handled.

The handling of units of some sort is the essential nature of the order picker's job. Therefore, almost all elements would be considered variable and each would require study. If two or more conditions varied simultaneously, the number of studies required could become economically prohibitive. As the number of variable conditions that must be accounted for increase arithmetically, the number of studies required could increase geometrically. For example, in the simple situation in which either of two carton sizes could be packed with one of two different products of varying weight, four studies would be required.

> 6. Regular and irregular elements should be separated. Elements that do not occur in every cycle should be kept separate to facilitate proper prorating. Often considerable observation is required to find them, but they are a valid part of the job.

The order picking cycle is regular only in that an order must be acquired before it can be picked, and picked and accumulated before it can be moved to a shipping point. Within these broad parameters of sequential regularity, a great deal of irregularity occurs. Although the element of walking is predictable, the distance to be traveled is difficult to predict. Having arrived at a new picking location, it is hard to estimate how long the order picker will stay since that period of time is a function of the number of units picked. Having picked the correct quantity, one would then need to predict whether the worker will move to another picking point or proceed to a shipping location.

<u>Other traditional approaches</u>. Examination of the aforementioned criteria, in light of the realities of the shipping environment, sug-

gests that the very nature of order picking may preclude the application of time study techniques. Further, as previously quoted, Nadler's observation that ". . . a standard time must be established for each basic motion with exactly the same procedures used in time study" constituted an impedance to the successful use of that technique.

Predetermined time systems constituted an evolution from common times for work elements to those for body movements. Moreover, they were not constrained by any given work environment. Still, they did not provide answers to the order picking characteristics cited above. There are two major problems in applying predetermined time systems. The first encountered relates to the length of the elements studied. As observed by Mayer:

> One external source of standard data is the so-called predetermined elemental time systems which have been developed by consultants, educators, and independent research workers. Some of these are the work-factor system, methods-time measurement, basic motion-time study, and motion-time analysis. In essence, each of these systems provides time requirements for elements which can be used to describe many manual activities. Their distinguishing characteristic is that the elements considered are much more basic and of much shorter duration than those considered in stopwatch time studies. In fact, they are on the order of therbligs. Because of the more fundamental nature of the elements, they can be used to describe a greater variety of jobs than can be described with the usual stopwatch time study type of element.
>
> One of the better known of these systems is methods-time measurement (MTM).[27] In this approach, use is made of time data compiled for the following basic activities; reach, move, turn and apply pressure, grasp, position, disengage, release, eye travel time and eye focus, and body, leg and foot motions.[28]

The application of these minute motion times to the order pick-

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[27]A detailed description of this system can be found in H. B. Maynard, et al., Methods-Time Measurement (New York: McGraw-Hill Book Company, 1957).

[28]Raymond R. Mayer, Production Management, 2nd ed. (New York: McGraw-Hill Book Company, 1962), p. 592.

ing function could be done only if a great number of assumptions were made. For example, the usual application of MTM is made upon a carefully engineered work place. In order to apply MTM (or any other predetermined time system), the distance moved by the hands must be known. The reach movement is graduated in one-inch increments from less than one to thirty inches. The body, leg and foot motions are differentiated according to the following descriptions, each having several different time values depending upon the circumstances:

Foot motion - hinged at ankle with heavy pressure
Leg or foreleg motion
Sidestep - Case 1 - Complete when leading leg contacts floor
Sidestep - Case 2 - Lagging leg must contact floor before next motion can be made
Bend, stoop, or kneel on one knee, arise
Kneel on floor--both knees, arise
Sit
Stand from sitting position
turn body 45 to 90 degrees
Case 1 - Complete when leading leg contacts floor
Case 2 - Lagging leg must contact floor before next motion can be made
Walk[29]

Assumptions. A number of assumptions would have to be made to apply these predetermined standards to the order picking function. First, the activity site of the order picker is constantly moving. Each line item on the order would indicate a different storage location; hence, potentially varying conditions. If the goods are racked, the first item may be in the front of the bottom rack while the second may be on top in the back. Second, if the goods are being accumulated on a movable pallet or carton, the first item might require stooping, while the last item picked might require only a simple waist bend. In order to consider all conditions, every possible circumstance would need to be anticipated,

[29]Maynard, Methods-Time Measurement, p. 211.

the standards applied, and some sort of grand average calculated. To do that, further assumptions would have to be made. This requirement leads to the second difficulty. Buffa states:

> Universal [predetermined] standard data give time values for fundamental types of motions, so complete cycle times can be synthesized by analyzing the motions required to perform the task. Fundamental time values of this nature can be used as building blocks to forecast the all-important time criterion, provided that the time values are properly gathered and that the various minute motion elements required by the tasks are analyzed perfectly.
>
> . . . Many people feel that universal standard data lead to greater consistency of standards, since analysts are not called on to judge working pace in order to develop a standard. This does not mean that judgment is eliminated from the use of universal standard data systems, however. A great deal of judgment is required in selecting the appropriate classifications of motion to use in analyzing an operation; an inexperienced person ordinarily will not be able to perform these selections accurately enough for the purpose of determining production standards.[30]

As was the case in the application of time study techniques, the inability to predict the sequential relationship of movements poses the most formidable obstacle to the use of predetermined time systems for setting the order picking function's performance standards.

A probability model base. The literature search uncovered a final unpublished source that attempted to overcome the unique difficulties described above in the shipping environment. The source suggested the following approach:

> An effective warehouse layout should minimize walking time. This is accomplished by first analyzing the distribution of warehouse items with respect to forecast demand. This analysis is so differentiated that a probability analysis in conjunction with the warehouse layout, the placement of goods is such that one may predict the sequential probabilities of filling an order having traversed one aisle, two aisles.

The logic quoted is based upon the assumption that, although line

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[30] Elwood S. Buffa, Modern Production Management (New York: John Wiley and Sons, Inc., 1969), p. 458.

items cannot be predicted with certainty as occurring in a given order, there exists a probability that certain items will occur more often than others. The basis for assigning a probability of occurrence on an order is an item-by-item sales forecast. This forecast is usually some extrapolation of demand from a previous period that may be modified by seasonal and cyclical variations or other knowledge of existing market conditions that could impact upon the item demand for the period in question.

Warehouse layout. This demand model is then used as the basis for the arrangement of goods in the warehouse. This is accomplished by an array of all items in terms of probabilities of occurrence. The most popular item would appear first on the list, the second most popular second, and so on. the goods in the warehouse are then arranged according to the array. If the first aisle (presumably the one nearest the loading dock) could accommodate twenty items, the first twenty items on the list would be placed in that aisle. It is assumed that, if the demand model is fairly accurate, the order picking activity level and locus of operation would be fairly predictable and therefore minimize the distance walked to fill an order. This approach, given an accurate prediction of demand, would probably fulfill that purpose. It would require the following, however:

1. That order pickers always start activity on the same aisle and proceed in a fixed pattern

2. That order pickers have detailed knowledge of item location since grouping of goods by product line will no longer be possible

3. That order pickers scan the entire order and be familiar with each item ordered or the orders be printed in the same sequence as the array of probabilities of demand

If the above approach is also to be used for the determination of performance standards, certain problems arise. It is true that the approach tends to minimize the completely random movement that was cited as the chief impediment to the use of traditional methods for the determination of performance standards. However, more problems remain.

The next step in the calculation of performance standards is to model order picker traffic patterns on the arrangement of goods in the warehouse. The purpose, of course, is to apply some predetermined standard for walking so that the elemental time for travel can be determined. The difficulty is that, while it may be possible to accurately forecast the probability of occurrence on a shipping order for each item in inventory, it is extremly difficult to predict the order in which they might occur. This latter point is important for the determination of an order picking standard since one must know the point at which the order picker begins and ends his activity in order to determine the travel involved.

Time constraints of a probability model. The model suggests that the same logic used in predicting the probability of demand be applied to predict the next item to be picked. this approach has validity only if the time period used as a basis for the standard calculation is extremely long. To illustrate, if a given item occurred on ten percent of all orders during the period used for the demand forecast, it does not follow--even though a given period was exactly predictable--that the item has a 10 percent probability of occurring on any given order. Unfortunately, there will always be chance, short-run fluctuations which would limit the pragmatic validity of that line of logic when used as a basis for individual performance standards.

The probability model approach represents an attempt to replicate the conditions detailed earlier that are prerequisite to the successful application of the Stopwatch, Standard Data, and Predetermined Time Systems approaches. It is important to recall that these approaches assumed that the environment is somehow repetitive and predictable. Most direct labor applications rely upon either a repetitive motion pattern and/or a substantive machine element upon which to base temporal prognostication.

These assumptions of repetitiveness and predictability are so critical that most union contracts covering incentives state that standards may be changed if an alteration is made in equipment, method and/or work place. When the last statement is considered in light of the dynamics of the shipping room floor, any standard would be put in jeopardy by seasonal and random demand fluctuations, stockouts, overruns and changes in product mix. The reason is that the occurrence of all or any one of these phenomena could cause an order picker to change his method of picking and accumulation. This consideration is so decisive that if one wishes to rigorously interpret the contract language, any one of these conditions would be sufficient grounds for a grievance directed toward a restudy of the standard. For example, should a pallet of goods not be put in the space assumed by the probability model cited above, there might be sufficient grounds for grievance.

If performance standards for order pickers are to be engineered, the methodology to be used lies outside what has evolved in the traditional vein. The following chapter explores reported advances in the quantification of indirect performance using techniques that return the observer to the work environment, but with a technique that reaches beyond the limitations of the Stopwatch, Standard Data, and Predetermined Time Systems.

A time study approach to order picking and accumulation standards. In this chapter the nature and characteristics of traditional time study methods have been examined. Although the research site will be examined more closely in a subsequent chapter, certain general statements have been made concerning the order picking and accumulation task. It is the purpose of this section to examine the considerations involved in applying traditional methods to the order picking and accumulation function. This hypothetical model will later be contrasted with the results of the writer's research.

When the order picking and accumulation function is reduced to a basic description, the following elements appear to be common regardless of the environment.

1. A source document is acquired that lists the items to be picked and accumulated

2. Items are selected and accumulated by moving through a storage area

3. The completed order is then moved to a staging area in preparation for shipment

It is recognized that the source document may range from simply a handwritten list to a computer-produced bill of lading. The items stored may be inside or outside, palletized, bin stored, conveyorized, etcetera. Movement through the area may be by walking, towmotor, truck, or any variety of means. The critical point is that regardless of the environment and the state of the material handling technology utilized, the order picker must know what is needed, locate it, accumulate it, and ready it for shipment.

The task of determining a standard for picking, and accumulation can be reduced to quantification of the following time values:

1. The time allowed to move from the point at which the source document is acquired to the point at which the first item picked is located

2. The time allowed to move from the location of the first item to the location of the second item, from the location of the second item to the location of the third, and so on, until the last item is picked

3. The time allowed to move from the location of the last item picked to a shipping point (or a point at which a new source document is obtained)

Determination of the number of standards required. If the assumption is made that the sequence in which the order is picked is the same as the sequence in which the items appear upon the source document, a general model can be used to determine the number of time studies required.

In the situation in which a warehouse contains only four item locations, a standard would be required for the time allowed to go from each of the locations below. (See 2 above.)

1. From location one to two
2. From location one to three
3. From location one to four
4. From location two to three
5. From location two to four
6. From location three to four

Six standards would be required to be set for the movements among locations.

The general formula for combinations of expected outcomes can be used to determine the number of time studies required for the determination of standards if the number of item locations is known. Since a combination is a set of N elements, the number of different combinations that can be formed from K elements is given by

$$C_{K\,n} + \frac{K\,!}{(K-n)\,!\;n\,!}$$

In the case discussed above, the formula would be applied by considering K equal to the four item locations with n equal to two. What is to be determined is the number of combinations of four-item locations that occur when they are taken two at a time. The combination formula is used rather than the one for permutations since the time from item location one to item location two is the same as the time allowed to go from item location two to item location one. The item locations must be considered two at a time since each standard involves a beginning point and an end point. Substituting into the formula the values K = 4, n = 2

$$C_{4\,2} = \frac{(4)\;(3)\;(2)\;(1)}{(2)\;(1)\;(2)\;(1)} = 6$$

<u>Model constraints</u>. In order to complete a general formula to determine the number of standards required, given the number of item locations, certain assumptions must be made about the acquisition of the source document and the movement that takes place after the last item is picked. This is necessary since the six studies calculated cover only the actual picking and accumulation activities. If the assumption is made that after the last item is picked, a movement is made to an order staging area where a new source document is acquired, a standard must be

calculated that quantifies the time allowed to move from each item location to the point at which source documents are acquired. The general formula for calculating the number of standards required for K item locations becomes

$$\text{Required Standards} = K + \frac{K\,!}{(K-n)\,!\;n\,!} = K + \frac{(K-1)}{2} = \frac{K\,[2+(K-1)]}{2} = \frac{K\,(K+1)}{2}$$

The number of standards required for the four-item example used is nine. Nine time studies is not an overwhelming task, but as the number of items increases, the job becomes formidable. The research site discussed later contained 1,400 item locations. The general formula, when applied to this environment, indicates that 980,700 time studies would be required.

Calculation and application. The standards required would most efficiently be calculated by developing standard data. This approach would substantially reduce the effort required to arrive at the standards. The calculation would be a one-time job, assuming that the location of the items was not altered. On the other hand, an equally formidable and continuing task is the application of the standards.

If the application of the standards was done manually, each line item would be considered in conjunction with the one that followed and the appropriate standard applied. If a computer was used to print the order, the application of the standards could be incorporated into the order entry system. Assuming the standards were a three-character number, the file required for storage--in addition to the problem of assessing that volume of data--would be beyond the capacity of most industrial computer installations.

In the final chapter the performance standard derived through this research will be compared with the traditional approach discussed above. Special emphasis will be placed upon the relative ease of application and maintenance of both standards.

CHAPTER II

LITERATURE SEARCH: NON-TRADITIONAL TECHNIQUES; INDIRECT PERFORMANCE STANDARDS

The dividing line between direct and indirect work can rarely be precise. In automation, for example, the only people involved may merely observe the control consoles and maintain the equipment. Old classifications of "direct" and "indirect" work would call these jobs "indirect." However, since they are the only ones operating in the activities, they could be considered the "direct" working force.

Definition of indirect work. Perhaps a better definition of indirect work is that it involves situations where a measure of output or work unit is difficult to establish. In many cases in industry, the work unit is difficult to establish or not directly observable--such as X number of units produced or so many cycles performed. Even then, some tasks with seeming direct measures of output are not direct work. For example, the number of pieces carried by a material handler on a fork truck can be counted or measured. Of course, this would not necessarily be the basis of a work unit for the handler because he may sometimes make several trips with half the number of units carried on other trips.

The literature, however, does consider many categories "indirect" work. These include tool room activities, materials handling, drafting, programming, office activities, engineering, maintenance, nursing activities, research and development, inspection, accounting, department store work, set-up personnel, housekeeping, managers and executives, and so forth. Nadler suggests that the term "nonrepetitive activity" best describes this category of work, and further states that this work segment is increasing.[31]

Whether the order picking function is direct or indirect activity is debatable. If the nonrepetitive criterion is applied to those areas of literature classified as indirect labor, interest in the techniques reported to set standards in those areas is heightened. For example, order picking is usually nonrepetitive.

Performance standards for indirect work. Early literature suggests that performance criteria for indirect work be established by finding the actual work unit and relating indirect activities to direct work output.

To determine a work unit for indirect work involves thorough investigation of possible relationships among the data obtained. Thus, the elemental standard data procedure is the basic approach recommended. For example, the fork truck operator may have a work unit related to number of trips, total pounds carried, distance or any combination of these. With predetermined motion-time systems, some available standard data, and a few time studies, a standard data arrangement may be developed for some indirect tasks.[32]

It was also suggested that some classes of indirect work could be related to the output of direct people. Indirect people in certain activities--like die setting, housekeeping, and material handling--can be

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[31]Nadler, Work Design, p. 355.

[32]A. M. Robinson, "Planned Repair Jobs Hold Down Costs," Factory, Vol. CXIX, No. 7 (July 1961), pp. 132-40.

included in the group and operate with the performance criteria and/or the incentive plan used for the people they service. Gold states:

> This is an easy way of establishing performance criteria, although it should not be used just for this reason. Many indirect work situations can still have individual performance criteria to permit each operator latitude for exercising his own abilities.[33]

For the reasons advanced in the previous chapter, predetermined time systems, standard data, time studies or any combination thereof, are not applicable to the order picking function. The second suggestion, i.e., relate the indirect task to some measurable direct task would appear to present insurmountable problems because order picking is usually quite remote from those activities that produce the items. Any relationship to direct labor effort would be tenuous at best.

Performance standards for nonrepetitive work. When later literature concerning the measurement of nonrepetitive tasks is examined, it becomes immediately apparent that the research to date has relied heavily upon work sampling.

> Work sampling is one of the most versatile tools for modeling nonrepetitive jobs. Before its advent, the study of nonrepetitive tasks was virtually nonexistent. Most nonrepetitive jobs involve people with skills in which they take pride. Many of them frequently complain that too many other activities do not let them utilize their skills. Work sampling does not offend the sensibilities of these people, and it provides a degree of motivation because something is being done to find a way to utilize the skills more effectively.[34]

The flexibility of work sampling provides a model for even the most nonrepetitive activities.[35] Specific applications include safe-

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[33] B. Gold, Foundations of Productivity Analysis (Pittsburgh: University of Pittsburgh Press, 1955) p. 123.

[34] Nadler, p. 335.

[35] R. L. Shell, "Work Measurement for Indirect Labor Activities," Industrial Management, Vol. XIII, No. 11 (November 1971), pp. 4-7.

ty,[36] research workers,[37] executives of the company,[38] supervisors,[39] accounting,[40] inventory control,[41] professors in a university,[42] computer programmers,[43] and hospitals (clinics, heart station, pathological laboratory, operating room, nursing stations, and many others).[44]

Broom summarizes the advantages inherent in work sampling, as against other means of producing similar information, as follows:

> 1. More information can be acquired in a given period than can be obtained by any other method (A production study would elicit only 20 to 30 percent as much information in the same period)

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[36] J. Maguire, "Work Sampling Sold Safety for US," Factory Management and Maintenance, Vol. CXIII, No. 2 (February 1956), pp. 92-93.

[37] J. S. Herrick, "Using Work Sampling to Study the Activities of Research Workers," Journal of Industrial Engineering, Vol. X, No. 1 (Jan.-Feb. 1959), pp. 60-63.

[38] C. L. Brisley, "Oral Communications in Executive Behavior in a Medium Sized Company in Detroit, Michigan," Ph.D. Dissertation (Wayne State University, 1957).

[39] J. S. Underhill, "First Line Supervisors--How Do They Spend Their Time?" Paper Number 56-A-54, American Society of Mechanical Engineers, Annual Meeting, 1956; G. Nadler, "What Do Your Foremen Do?" Mill and Factory, Vol. LIII, No. 4 (October 1953), pp. 88-92.

[40] A. C. Rosander, "Selected and Annotated References on Sampling Applied to Accounting Problems," Industrial Quality Control (June 1960), pp. 11-18.

[41] B. M. Bowles, "Application of Statistical Sampling Techniques to Life Inventory Evaluation," Accounting Review, Vol. XXIV (April 1954), pp. 244-250.

[42] J. A. Ritchey, "An Unusual Work Sampling Application," Journal of Industrial Engineering, Vol. X, No. 6 (Nov.-Dec. 1959), pp. 450-455.

[43] Detailed analysis of applications of work sampling to computer programming can be found in D. A. Heckerman, "A Computer Program Development time Estimation and a System Development Time Estimation Methodology," Ph.D. Dissertation (University of Cincinnati, 1976). See also R. L. Shell, "Work Measurement for Computer Programming," Industrial Engineering, Vol. IX, No. 10 (October 1972).

[44] D. Littauer, "Industrial Engineering in the Hospital," Hospitals, Parts I and II (February 1960).

2. Workers observed seem to resent the work sampling observer less than they resent an engineer making a production study (perhaps because he is not present continuously)
3. The information provided by work sampling is sometimes unobtainable by any other method or, at least, is impractical to procure by any other method
4. The information yielded by work sampling typically is accurate
5. Relatively untrained observers may be used to assemble data by work sampling (Each supervisor can study his own department; in fact, self-observation is possible.)[45]

Work sampling does, however, present some problems of application which must be solved. These problems can be summarized as follows:

1. An unbiased sampling process must be used
2. Qualitative classification of observations is required
3. Some knowledge of statistical theory is required in setting up the work sampling study
4. When work sampling is utilized to develop production standards:
   a. A rating factor must be determined
   b. Allowances must be determined. (These problems exist when other methods of standards developed are used; thus, they are not unique to work sampling)

The utility and flexibility of work sampling may be demonstrated by its use in the study of a nonrepetitive work situation which was reported by Robert J. Paul.[46] The technique was used for the analysis of the activities of salespeople in a retail store, and the data were collected by direct observation of randomly selected departments at random

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[45]N. H. Broom, Production Management, rev. ed. (Homewood, Illinois: Richard D. Irwin, Inc., 1967), pp. 261-284.

[46]Robert J. Paul, "Performance Standards for the Non-Manual Non-Repetitive Activity?" The Journal of Industrial Engineering, XIX, 12 (December 1968), pp. 612-617.

instants in time.

Subsequent to the determination of standards, the data were tested and finally utilized to reschedule salespeople with a net result of a $300,000 decrease in payroll costs without loss of customer service. Having utilized this approach in a number of retail outlets, Paul draws the following conclusions:

1. The method (work sampling) is adequate to examine the hypothesis that it is possible to establish accurate, low cost performance standards for nonrepetitive activities
   a. The work of the nonrepetitive employee can be defined in terms of elements which are meaningful to the employee and also related to the major objectives of the firm
   b. The method can be applied to determine how each individual worker spends his time as well as how the group spends its time
   c. The data gathered from the studies are reasonably accurate, and limits of accuracy can be determined by statistical methods
   d. The method produces information that might not be obtained by other methods
   e. Managers are interested in studies of this type and want to know how their employees spend their work day. Managers will accept the findings of this type of study and are cooperative in its conduct
2. Administration of the technique is simple
   a. Data can be obtained without disturbing the workers. The method produces a minimum of distortion of normal operating routine
   b. Data can be obtained either by department managers or by outside personnel. Observers need not possess an intimate knowledge of the business. Self-observation is also possible.
3. The method provides an efficient way of gathering data
   a. If the purpose of the study is to determine how a group of employees spends its time, the study can be completed in five days
   b. A study to determine how individual employees spend their time may take longer depending on the number of persons observed and the number of observations made in a day
   c. A study to determine an accurate performance standard would also vary in duration depending on the factors just mentioned
   d. The length of time needed to complete a study using work sampling is much less than that required by time study methods
4. The method is economical to administer
   a. Only the observer's time was invested in the studies conducted
   b. The use of data processing equipment, if already available, could reduce processing time by about 25 percent[47]

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[47]Ibid., p. 617

Work sampling methods. In conducting a work sampling study, the analyst takes a comparatively large number of observations at random intervals. The ratio of the number of observations of a given state of activity to the total number of observations taken will approximate the percentage of time that the process is in that given state.

For example, if 10,000 observations at random intervals over a period of several weeks indicate that a given automatic screw machine was turning out work in 7,000 instances, and in 3,000 instances it was idle for miscellaneous reasons, then it would be reasonably certain that the down time of the machine would be 30 percent of an 8 hour working day, or 2.4 hours, and the effective output of the machine would be 5.6 hours per day.

The accuracy of the data determined by work sampling depends upon both the accurate classification of elements and the number of observations taken.

Element classification. In its embryonic stages, work sampling was known as ratio-delay because the results were reported as the ratio that resulted when the number of delay observations were divided by the number of working observations. The element description therefore was simply a bi-modal set, i.e., "working" or "not working." As the discipline became more refined, more than two elements were observed. As more elements were observed, classification of the elements became increasingly important. For example, the basic question of exactly when an element begins and ends must be answered prior to observation. Although some areas of work pose few problems with respect to classification, the area of maintenance activity is particularly resistant to definitive classification. To demonstrate the importance of classification and how it was handled in a study of maintenance activity, the following research by Floyd S. Meck, Jr.[48] is presented.

Application of element classification. The objectives of the Meck study of maintenance work were to:

1. Determine the current work effectiveness of the maintenance division craftsmen

2. Develop recommendations to improve work effectiveness

3. Review the accuracy of time standards that had been established much earlier. (Many changes in methods, machines, tools, and maintenance procedures had occurred since the original earned-hour incentive plan was installed.)

Each productive and non-productive category was completely described, with examples, in writing and given to observers for study and reference. Two examples of category descriptions follow which illustrate the detail of explanations used by Meck:

> Productive work is the active procedure of producing or accomplishing an assigned task and working toward its completion
>
> Motion may or may not exist depending on the nature of the work. (For example, a man holding a wrench on a bolt, while another holds it in; or opening a press; or raising a lift; or spot welding; or holding a ladder, while another works on the ladder, is considered productive work.)
>
> All time between "preparation" and "cleanup," not covered by elements classified as non-productive, is considered productive time. (For example, a man cleaning a tool, while performing a job not yet completed, is considered productive work.)
>
> Walking between the job and a work cart or motorized vehicle, or walking within the immediate vicinity of the work area is considered productive time
>
> "Attention time" is time spent physically attending a machine doing productive work (no direct work being contributed by the man). While attending, the man may be doing a nonproductive element such

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[48]Floyd S. Meck, Jr., "Work Sampling Study of Scattered Maintenance Workers," Industrial Engineering (January 1972), pp. 20-23.

as reading, non-business talking, smoking, etc.[49]
. . . Personal time is an element that can definitely be determined as a person walking to or from a washroom, vending machine, drinking fountain, cafeteria (or in a cafeteria), dispensary, personnel, or smoking area

A person in a smoking area at a non-break time

A person eating and standing by a machine where nothing is being done and no tools are involved

A general rule to follow is: personal time, allowable comprises those elements which the company allows within the pay structure, and which are necessary to the man's immediate needs

The personal time element may occur only in the factory or offices, not in the craft shop of that maintenance man.[50]

The data were summarized by totaling the number of observations by each productive and nonproductive element for each craft. From this summary an analysis of the performance of each craft was made. In itself, the body of data provided a clear picture of work effectiveness for each maintenance craft as well as for the division as a whole.

Work sampling theory. The theory of work sampling is based on fundamental laws of probability. If, at a given instant, an event can either be present or absent, statisticians have derived the following expression which shows the probability of x occurrences of an event in n observations:

$$(p + q)^n = 1$$

p = the probability of a single occurrence

q = (1 - p) the probability of an absence of occurrence

n = number of observations

If the above expression, $(p + q)^n = 1$, is expanded according to the Binomial Theorem, the first term of the expansion will give the probability that $x = 0$; the second term $x = 1$; and so on. The distribution of these probabilities is known as the Binomial Distribution. Statis-

[49]Ibid., p. 22.

[50]Ibid., p. 23.

ticians have also shown that the mean of this distribution is equal to np and the variance is equal to npq. The standard deviation is equal to the square root of the variance.

The distribution is useful because a given condition of work (element) either is or is not present when an individual observation is made. If the element is not being performed, all other possible conditions are treated simply as a non-occurrence of this element.

Binomial Distribution. As the number of observations (n) becomes large, the Binomial Distribution approaches the Normal Distribution. Since work sampling studies involve quite large sample sizes, the Normal Distribution is a satisfactory approximation of the Binomial Distribution. Rather than use the Binomial Distribution with a mean of np and a standard deviation of $\sqrt{npq}$, the distribution of a proportion with a mean of p is used (i.e., $\frac{np}{p}$) and a standard deviation of $\sqrt{\frac{pq}{n}}$ (i.e., $\sqrt{\frac{npq}{n}}$). In a work sampling study, a sample of size n is taken in order to approximate p. According to sampling theory $\bar{p}$ ($\bar{p}$ = the proportion based on a sample) of each sample cannot be expected to be the true value of p. However, the $\bar{p}$ of any sample can be expected to fall within the range of $\bar{p} \pm 2$ sigma, approximately 95 percent of the time. In other words, $\bar{p}$ can be expected to fall outside the limits $p \pm 2$ sigma only about 5 times in 100 due to chance alone.

In random sampling procedures, there is always the chance that the final result of the observations will be beyond the acceptable tolerance. These sampling errors will diminish as the size of the sample increases. The sampling error of a sample percentage may be expressed by the following equation:

Standard deviation of a percentage = $\sqrt{\frac{p(1-p)}{n}}$ where p = true percentage occurrence of the element being sought expressed as a decimal

n = total number of random observations

By approximating the true percentage occurrence of the element being sought (which is designated as p) and knowing the allowable standard error permitted, it is possible to substitute back into the above expression and compute n.

For example, assume a researcher wants to determine the number of observations required with 95 percent confidence so that the true proportion of personal and unavoidable delay time is within the interval 6-10 percent. It is expected that the unavoidable and personal delay time encountered in the study is 8 percent.

In this case, p would equal .08 and the standard deviation of the sample percentage would equal 1 percent or .01. Using these values, n can be calculated as follows:

$$n = \frac{.08(1 - .08)}{(.01)^2}$$

$$= 736 \text{ observations}$$

Confidence interval. Frequently it is desirable to express the interval of the element being sought as a percentage element tolerance, rather than an absolute percent. This is especially true when the element is small and the absolute interval might equal or exceed the true element percentage. If the element percentage is 8 percent an interval of an absolute $\pm$ 10 percent would be misleading. In the example given, a $\pm$ 25 percent element tolerance is used (.02/.08). After the initial estimate of the number of observations has been obtained, a more accurate estimation of p may be computed. By using the above equation, again, the achieved accuracy is computed. If the achieved accuracy is as good or better than the desired accuracy, $\bar{p}$ is accepted as the true value of the population value "p." If the desired accuracy has not been obtained, more observations are taken and the process is repeated.

Although the basic sampling theory has been known, the real impetus for its application to work measurement was provided by the computer. The discussion which follows will demonstrate the use of the theory when applied in conjunction with the computer.

Impact of the computer upon work sampling. With reference to the computer, Henry found it valuable not only to process the observations but also to initiate the study and provide ongoing feedback concerning the confidence level being achieved at any point in the study. The often-used theory below is applied to determine how many observations should be made in a work sampling study to achieve $\pm$ 5 percent confidence level:

$n = 1537\ (\bar{p})\ (1 - \bar{p})$ where

n = the total number of observations, and

$\bar{p}$ = the number of occurrences of the activity being studied divided by the total number of observations.

Two problems arise, however.

1. What should be the estimate of p?

2. If the study is terminated before the desired number of observations, what will be the level of accuracy at that point?

A relatively simple program (70 Fortran statements) was formulated. Sampling data were accumulated on a Fortran coding sheet as observations were taken. Input data were keypunched directly from these sheets. After the program is run, the individual input data as well as the old matrix are disregarded since all that is needed for the next run is the new matrix which is punched onto cards during the program run. The computer program is run every few days. The output not only indicated what the confidence limits were at the 95 percent confidence level, but how many observations were required to reach $\pm$ 5 percent confidence limits for each activity.[51]

This approach obviously eliminates the need to estimate the p value prior to the study.

A similar computer application was used by the Naval Weapons Station at Seal Beach, California. The aim was to increase efficiency and develop data necessary to reevaluate staffing allocations. A computerized work sampling approach was chosen. For purposes of work sampling, data identification, collection, and computation, the following control factors were made an integral part of the study:

1. All observations were construed as falling into one of five major element groupings, each of which has its own coded work elements. The five groupings were: productive, non-productive non-avoidable, non-productive avoidable, personal and out-of-area
2. In addition to the measurable productive work elements, a special out-of-scope element was established to cover productive work performed that could not be directly related to a specific work unit
3. IBM Port-a-Punch equipment was used to record observed data
4. A computerized data computation system was specially programmed for processing the data compiled[52]

The computer produced the listing of the number of observations and indicated the percentages of observations as applied on a daily and cumulative basis. The weekly printed report included a breakdown by individual element codes, recorded on a daily and cumulative basis, for each area. It also provided a summary of the five major categories by

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[51]David P. Henry, "Computer-Aided Work Sampling," Industrial Engineering (July 1973), pp. 14-16.

[52]Eric Frank, "Low Cost Standards for Indirect Labor," Industrial Engineering (August 1970), pp. 27-29.

day and a cumulative summary for each area. In addition, a summary was printed indicating the percent of observations as a total for the department as a whole. Cumulative confidence levels by area and for the department were computed and printed as part of this report. The random observation sheets were computed and printed by computer.

Standards were developed for each productive work element which included the raw time per unit and adjustments for personal allowance, unavoidable delay, and a leveling factor. The relative value of each work element was then established by percentage of occurrence. The selection and use of one of the established work elements and its application as an overall control standard was then made possible because of the interrelation of all elements in contributing to the performance of the department's basic functions. This control standard is used as a tool for measuring department performance efficiency and thereby becomes a staffing guide.

Other applications of work sampling. Heiland and Richardson[53] set forth a proposition pertaining to all work sampling. Its essence is that the percentage of observations that find an employee or machine idle, working, or in any definable and observable state, reflect with a known degree of accuracy the average percentage of time actually spent on that element in that universe of work. The only prerequisite prior to reaching the above conclusion is that sufficient observations be randomly collected over a sufficient period of time. ("Sufficiency" will be discussed later in the chapter on methodology.)

Early applications of the proposition above were reported by Wolf

[53]R. E. Heiland and W. J. Richardson, Work Sampling (New York: McGraw-Hill, 1957).

and Riordan.[54] They studied the activities of non-supervisory and supervisory engineers. The historical importance of their study lies in the fact that it established that work sampling techniques could be used to study professional personnel.

Geisel[55] expanded upon the methodology of Heiland and Richardson to study supervisory work. In this study three techniques were used to gather and verify the data. Work sampling was used as the primary research technique. All-day time studies were randomly used to cross verify the data. All-day time studies were randomly used to cross-verify the results of the work sampling. And, finally, personal interviews were conducted with the foremen in an attempt to elicit their reasons for allocating their time as they did. This represented the first reported combined use of time study work sampling and personal interview in the study of supervisory activity.

Although most work sampling applications reported involve a mass of data collected from the observation of a large number of people and/or machines, Beegle and Bricker report a successful application of the work sampling techniques to the study of the activities of one person. They state:

> Direct measurement by ordinary time study methods hardly suffices in highly nonrepetitive indirect labor areas. The cost of direct measurement in these areas would eventually outweigh any benefits derived from the incentives. This is especially true where only one or two indirect people are involved. To establish indirect labor standards, in such a case, that are economical to use and still give a satisfactory measure of the work content, we used work sampling

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[54] M. Wolf and D. P. Riordan, "Work Sampling in an Engineering Design Department," Journal of Industrial Engineering, 12 (May-June 1961), pp. 175-181.

[55] J. M. Geisel, "A Method for Measurement and Analyses of Supervisory Work," Journal of Industrial Engineering, 19 (April 1958), pp. 175-185.

and multiple correlation analysis.

The area of study in this case was the tool crib in a welding department. The attendant's work is essentially maintaining productivity of direct labor employees in the welding department. It was felt that some variables are necessary which have an influence on the amount of work the welding tool crib attendant does. These were found through careful analysis during an eight-day work sampling.

The study revealed that the variables controlling the work of the crib attendant were direct down time; direct labor earned hours by the production employees; and the number of weld setups completed by the crib attendant. When the direct labor down time increased, more work content was noted in the crib attendant's work elements. Similarly, when the direct labor earned hours increased, the productivity and turnover of weld jobs rose, resulting in further work for the crib attendant. The same was true for setups completed.

The problem, then became one of determining a methematical model that would correlate the allowed hours to perform the crib attendant's work with the three variables. Assuming their independence, a mathematical model was developed using the method of least squares. Application of an analysis of variance indicated that the correlation (0.983) did not occur by chance.

The incentive plan has been in effect long enough now to conclude that it is working. The authors' report recommends that the same technique be applied to tool crib attendants in other operating departments of the plant.[56]

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[56]B. B. Beegle and T. J. Bricker, "One Man Incentive Plan," Industrial Engineering (August 1972), p. 21.

Analysis of variance in work sampling data. In the previous discussion, it was demonstrated that work sampling could be effectively utilized to determine the proportion any element constituted of a given activity pattern. It can and has been used in those areas in which traditional methods were either not applicable or too expensive. Although knowledge of the proportion each element of a given activity pattern represents is valuable, work sampling leaves unanswered the question of why each element constitutes a given proportion.

For example, in the study of the tool crib attendant, work sampling simply quantified a number of elemental times. The causative relationships between these elements and the activities of the tool crib attendant and his work environment remained unanswered. It should be noted that these causative variables were outside the activity pattern of the attendant. In fact, most human activity called work is affected by a number of variables, some of which are endogenous, but most of which are exogenous to the work itself, being largely a function of the environment in which work is done.

In the determination of a measurement or unit of work, it is often necessary to understand the relationships that exist between the unit of work and the variables that are affected by or affect it. Classic time study approaches recognized this requirement. Jelinek and Steffy[57] commented on the time study approach and some of its restrictions.

> In their work [however] the classical operations analysts and time study practitioners have found it useful to obtain the relationships between some of the factors under investigation. When only two factors are considered, the approach used has generally been

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[57]R. C. Jelinek and W. Steffy, "Use of Multi-Variate Techniques for the Analyses of Work Measurement Data," Journal of Industrial Engineering (February 1966), p. 106.

> simple in nature, consisting of plotting data points on a graph and fitting a curve through the points thus obtained. The problem becomes more cumbersome when the effects of two or more independent variables on the dependent variables are to be investigated, but the practitioner still has been able to cope with this problem by investigating the effect of a single independent variable while holding the remaining ones constant. In addition to the practical difficulty of keeping certain variables constant, this approach requires a large amount of data.
>
> The use of this approach makes it impractical to consider more than two or three independent variables simultaneously. As a matter of fact, the complication brought about by the consideration of only a second variable usually leads the practitioner to simplify the representation of the real situation by considering the effect of only one independent variable. An example of this is in the area of performance rating. Although the performance factor consists of variables such as the operator's work pace, his aptitude, his motivation, and his skill, the rater generally judges the net effect of all these factors on the performance time without considering the effects of the individual variables.

The approach recommended by Jelinek and Steffy is multivariate regression analysis. This approach has been applied by others to the measurement of work that was felt to be affected by a number of independent variables. The reasons this approach shows promise are explained next. A brief description of the theory will precede a discussion of specific applications of the technique to work measurement.

Theory of regression analysis. Regression analysis is the procedure that attempts to derive a numerical relationship between two groups of matched observations so that, by having information about one, the value of the other can be predicted. The procedure is therefore designed to reveal:

1. The nature of the relationship between two variables, that is, what formula can be used to determine one from the other

2. The strength of the relationship, that is, how widely deviant are the real values likely to be from the predicted ones

3. How well the observed sample of values replicate the real na-

ture of the relationship; that is, whether a large enough sample has been observed so that the real relationship will not be distorted by one factor varying independently from the other(s)

Although there is a statistical relationship between regression and correlation[58] regression can express the relationship between two variables without reference to correlation. Regression is best determined by the method of least squares which keeps to a minimum the deviation of observed points from the regression curve. The equation for straight-line regression is:

$$Y = a + bX$$

a (the Y intercept) and b (the slope of the line) are found by simultaneous equations:

and
$$a = \frac{\Sigma X^2 \Sigma Y - \Sigma X \Sigma XY}{n\Sigma X^2 - (\Sigma X)^2}$$

The equation for parabolic regression is:

$$Y = a + bX + cX^2$$

and the simultaneous equations involved in finding a, b, and c are:

$$\Sigma Y = na + b\Sigma X + c\Sigma X^2$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 + c\Sigma X^3$$

$$\Sigma X^2 Y = a\Sigma X^2 + b\Sigma X^3 + c\Sigma X^4$$

In the discussion above, only two variables were considered. One of these was the dependent; the other, the independent variable. The first

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[58]E. C. Bryant, Statistical Analysis (New York: McGraw-Hill Book Co., Inc., 1960), p. 133.

purpose of the analysis was to construct an equation with which to estimate values of the dependent variable from given values of the independent variable. This is the regression equation. The second purpose is to measure the closeness of the relationship between the two variables. This is done by means of the coefficient of correlation and its square, the coefficient of determination.

Frequently, estimates of one variable made from values of one other variable are not sufficiently close to be satisfactory, and it is often also the case that there are other possible independent variables which help in the estimation of the dependent variable. This is especially true of nonrepetitive tasks whose elements and elemental times may be dramtically influenced by independent variables that are exogenous to the work itself. Multiple regression analysis makes it possible to use more than one independent variable at the same time. Often, when two or more independent variables are considered jointly, the estimating procedure is far more accurate than when only one independent variable is used. The coefficient of multiple correlation measures the closeness of the relationship between the dependent variable and the joint simultaneous configuration of independent variables.

The methods for multiple regression usually begin with the assumption of linearity in the relationship among the variables. This assumption can often be verified or disqualified by simply plotting. When the relationships are non-linear, one or more variables are transformed into functions for which the relationships are linear.

The equation (assuming three independent variables) for multiple regression is:

$$X_{1(234)} = a + b_2X_2 + b_3X_3 + b_4X_4$$

$X_{1(234)}$ is the value of X_1 estimated from the regression in which X_2, X_3, and X_4 are independent variables

$a_{1(234)}$ is the constant in the multiple regression equation in which X_1 is the dependent variable, and X_2, X_3, and X_4 are the independent variables.

b is identified by subscript of the independent variable of which it is the coefficient

An example of the use of regression analysis in work measurement. The problem in this illustration was to estimate the time required to produce spools of fabric. The fabric in its initial form consists of a large rectangular piece of material called a "web." The web is cut or divided into strips called "bands" which are then wound onto spools and shipped to customers.

The time required to wind each spool depends on a large variety of factors. The type of material is one for the spooling machine operator handles cotton, nylon, orlon, nylon-banlon, and nylon acetate differently. The bands have a multitude of widths and lengths that also affect spooling times. In addition, some bands are sewn end-to-end or would side-by-side on a spool. Other influential factors include the type of wind; the part of the web from which the band was obtained; the method of creating the bands (cut or thread drawn); and the number of specific operations needed for each band. These factors are listed below.

Band width
Number of bands sewn end-to-end on each spool
Band length
The part of the web from which the bands were obtained
A time code to indicate whether the job is standard or off standard
The type of fiber, i.e., cotton, nylon, orlon, etc.

The number of bands wound side-by-side on a spool
Any special sewing needed for each band
The type of web-thread drawn or cutter
The surface area of the bands

The list does not include all possible factors related to the problem; however, it does contain those factors thought most important.

The traditional way of handling this kind of problem would be to isolate each independent variable and exclusively study it. Therefore, for each of the factors listed above, a separate study would be taken. Since the factors are not mutually exclusive, the number of combinations possible present a time study task of imposing proportions.

It is also interesting to note that some of the independent variables are quantitative and some are qualitative. This approach allows the researcher to enhance the empirical validity of the model. The quantitative variables have measurable values. Abranovic, who conducted the research, handled the qualitative variables by assigning values of either 0 or 1 to indicate the presence or absence of the attribute. Also, additional variables were considered in the analyses which were transformations of the original variables.

Regression analysis provided a practical means for combining subsets of factors in the list as estimates of production time. The dependent variable was defined as y_i. The subscript i denoted the particular observation on the time to wind a spool. Historical data included n observations of y_i and the independent variable defined as $x_{i,1}$, $x_{i,2}$, . . . , $x_{i,k}$, where i = 1, 2, . . . , n. The estimate of the dependent variable was written y_i, and defined as:

$$y_i = b_0 + b_1 x_{i,1} + b_2 x_{i,2} + \cdots + b_n x_{i,k}$$

The values for the b's were calculated from historical data using the method of "ordinary least squares."[59]

Selection of independent variables. One of the most fundamental problems that a researcher faces with this method (or any work measurement approach) is the selection of a subset of independent variables to be included in the prediction equation. A number of literature sources are available to aid in this decision. A most fundamental and comprehensive discussion is given by Draper and Smith.[60] More current and specific considerations involved in choosing the "best" subset are given by LaMotte and Hocking,[61] Kennard,[62] and Gorman and Toman.[63] On the other hand, Furnival[64] proposes methods for computing all possible regressions. The problem of choice of variables has also occupied researchers in the social sciences. For example, Beale, Kendall, and Mann[65] explored the implications of discarding variables in the interpretation of biological data.

For the textile problem just discussed, 800 observations were

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[59]Wynn A. Abranovic, "Production Time Estimates for Spooled Fabrics," Textile Research Journal (August 1974), p. 574.

[60]N. R. Draper and H. Smith, Applied Regression Analysis (New York: John Wiley and Sons, 1966).

[61]L. R. LaMotte and R. R. Hocking, "Computational Efficiency in the Selection of Regression Variables," Technometrics, 12 (1970), p. 83.

[62]R. W. Kennard, "A Note on the C_p Statistic," Technometrics, 13 (1971), p. 899.

[63]J. W. Gorman and R. J. Toman, "Selection of Variables for Fitting Equations to Data," Technometrics, 8 (1966), p. 27.

[64]G. M. Furnival, "All Possible Regressions with Less Computations," Technometrics, 13 (1971).

[65]E. M. L. Beale, M. G. Kendall and D. W. Mann, "The Discarding of Variables in Multivariate Analysis," Biometricka, 54 (1967), p. 357.

made on spooling time and related factors. Four hundred observations were taken for the bands that were divided using draw thread, and another 400 were taken for bands that were cut from the web fabric. The former were called thread-drawn web data and the latter cutter web data. Some of it produced equations of a predictive nature; the remaining were used for the validation of results.

The data were analyzed in three ways. Thread-drawn web data only; cutter web data only; a mixture of thread and cutter web data. In each case a multivariate regression equation was calculated. It was decided that a correlation coefficient of R, greater than or equal to 0.7, and a standard error of the estimate less than one third of the overall mean indicated a favorable response estimator.

Under the criteria set forth above, the results demonstrated that the thread-drawn web data only, and the mixture of thread-drawn and cutter web data, were good for prediction purposes. Those factors which appeared frequently as significant independent variables were: the time code (to indicate whether a job is standard or not); the fiber type; multi-rows of bands; the square root of the quantity-number of bands sewn end-to-end multiplied times the band length; and the web part. The fact that these factors were shown to be highly correlated with the production time provided useful information for both performance appraisal and production scheduling. In the words of the researcher: "The results provide the basis for establishing a work incentive system."[66]

Regression analysis has been demonstrated to be a powerful tool in many research efforts. Industrial engineers are just beginning to

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[66]Abranovic, p. 577.

appreciate its potency for analyzing and understanding those areas of work which refuse to be bounded by the normative parameters of traditional time study. Before it is embraced as a panacea, the observations of Crocker should serve as a caveat.

> Despite the forebodings of the timid, regression analysis is coming of age in industrial engineering. It is helping the change agent and the absorber-of-uncertainty to better understand the complex system in which he operates. When treated with proper respect and understanding, useful exploration can be undertaken with regression techniques that are not possible any other way.
>
> A Final Plea
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> Regression is held in ill repute by many for good reason. Through abuse and ignorance, analyses bordering on statistical larceny have been conducted, both to furnish and digest data. A regression analysis is about as prohibitive as a phone call. But the conclusions drawn will be no better than the data, care and thought that are invested. Successful analysis demands a carefully chosen goal, a thorough knowledge of the elements of the system, and a carefully conducted diagnostic evaluation at each step. The first step in curing any disease is the recognition of its presence.[67]

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[67] D. C. Crocker, "Intercorrelation and the Utility of Multiple Regression in Industrial Engineering," Journal of Industrial Engineering (January 1967), p. 84.

CHAPTER III

HYPOTHESIS AND RESEARCH SITE

Having reviewed the limitations of traditional work measurement techniques and the theory and application of work sampling and regression analysis to nonrepetitive work, the major hypothesis of this research shall now be stated.

The major hypothesis is based upon the assumption that traditional time study methods and non-traditional methods for measuring nonrepetitive work are, in and of themselves, insufficient for the determination of work standards for the order picking and accumulation function. It holds that by combining time study, work sampling and regression analysis, efficient and effective work standards for the order picking and accumulation function can be established.

To demonstrate the validity of the above hypothesis, a research site was chosen that evidenced characteristics commonly found in order picking operations. The site is described next in some detail to dimension any environment constraints to broader application of the methods used.

Background. In order to make the results of this research as widely applicable as possible, the following criteria were established for the research site. The product that is picked and shipped must be:

1. Manufactured to stock rather than to order
2. Subject to seasonal and random demand

3. A consumer good

4. Relatively low unit cost

5. Characterized by a wide range of discrete and different items

The rationale for establishing the above is as follows:

1. Goods that are made to order are often not stored and hence do not present the problem of classification, storage and subsequent retrieval that dictates the patterns of movement of order pickers

2. Constant demand patterns tend to stabilize an order picking work force. By seeking out a product with a fluctuating demand, the man-power planning considerations could be incorporated into the research

3. A consumer good was desired since it was more likely to evidence more dramatic demand variations

4. A low unit cost good was sought so that any given order might have as great a mix of items as possible

5. A large number of different items carried was thought to be the most challenging test for the research model being developed

<u>Characteristics of site</u>. The research site finally chosen was the shipping department of a midwestern company that manufactures and distributes window shades. The goods are shipped directly from the factory to retailers in every part of the country. From the point of view of satisfying the criteria established above, all orders were filled from inventoried stock; no item cost more than $6.00 at the retail level; and 1,400 discrete and different shade items were carried in stock.

<u>Manufacturing process</u>. The manufacturing process consisted of drawing bulk vinyl or vinyl-coated material from stock. This material is mounted on a large spindle and, as it is unrolled, exact shade sizes are cut and stacked on a truck. The cut stock then moves sequentially through

operations that (1) sew (or heat seal) a flap on the bottom to enclose a wooden stock, (2) mount the shade to a roller, and (3) occasionally sew or trim the bottom. The finished shades are wrapped in a plastic sleeve, then packed six shades to a carton. The cartons are manually removed from the conveyor and stacked on pallets. When the pallets are full, they are moved by lift truck to the storage area where all goods remain until picked to fill customer orders. In large measure the process could best be described as a conversion rather than a production operation. The only part that is manufactured, in the traditional sense, is the roller. Wood dowels are turned and drilled, wire is wound into springs, and coil steel is stamped and pierced to make components for assembly into the roller.

Product mix. As stated previously, 1,400 finished shade products appear in the company's catalog. These products are differentiated by color, gauge, size and, in a small portion of the product line, by special trim. These shades are all made from slightly over one hundred different colors and gauges of vinyl that are carried as a raw materials inventory. Generally, any one type of raw material vinyl could appear in an average of fourteen different finished goods items, while the most popular raw material vinyl is so differentiated that it appears on twenty finished products. In other words, by varying size, trim, roller type and packaging, one hundred types of viyl become 1,400 discretely identifiable finished goods items.

Raw material. It is important to point out that the average in-process time--from the issue of a manufacturing order, until receipt of the goods on the shipping floor--is less than twenty-four hours. (The plant operates on a three-shift basis.) This unusually short in-process time is in contrast to the time that elapses from issuance of a purchase order to the arrival of the raw material.

Because all of the unfabricated vinyl goods are purchased from Taiwan, the in-transit time from issue of the purchase order to receipt of the raw material varies from four to six months. This unique logistical consideration makes the determination of order point and order quantity for each finished item rather delicate. For, in addition to the usual worries related to setup, ordering and carrying costs, the decision maker must be concerned with the impact a finished goods decision has upon the raw material inventory.

For example, if it is decided to increase both the order point and order quantity for a given finished item, it follows that more raw vinyl will be used for that item than previously. This means that less of this vinyl will be available for other finished goods that could have been fabricated from it.

Inventory policy. Although this point seems readily apparent, it was not considered in the firm's formulation of inventory policy. A brief history may be helpful here. The inventory decisions that related to the reorder point and reorder quantity for finished goods were organizationally under the aegis of the vice-president of sales. His customary reaction to a finished goods' stockout was to increase the amount requested from manufacturing and to increase the frequency with which requests were made. (Both the order quantity and order point were increased.) This alternative solved the short-run problem of the item in question but in many cases created long-range difficulties for those items that required the same raw material vinyl.

Organization changes. Late in 1971, the order quantity and order point responsibility was taken from the vice-president of sales and assigned to the vice-president of manufacturing. The latter immediately established a Production and Inventory Control Department. At the same time, he commissioned the Industrial Engineering Department to conduct an intensive study of the Shipping Department.

The study indicated that the Shipping Department had grown in a rather haphazard manner. The first order of priority was an in-depth study of the manner in which orders were accumulated and of the impact the physical layout had upon both the efficiency and effectiveness of order accumulations.

The procedure for shipping was standard. The orders for the following week were sent from the computerized Order Processing Department on Friday evening. The eight pickers were issued a stack of orders each morning and worked on them until they had finished. No work was allocated by the department foreman nor was a record kept of the number of orders accumulated by each man.

With an order in hand, the man would seek out the goods desired. There was neither logic nor consistency about the location of an item. When a pallet of finished goods arrived in the department, it was placed in any location that was available. Having located the goods, the order picker would move his pallet to the location by means of a manually operated pallet mover. All cartons contained six shades and were of uniform size. Having loaded the proper number of cartons from the storage pallet to the accumulation pallet, he would proceed to the next item. This sequence of operations continued until the order had been completed.

At this time the order was banded to the accumulation pallet. A shipping stencil was cut from the information detailed on the order and each box top was stenciled. the pallet moved to the accumulation area to await pickup. The process was repeated for each order.

At the same time that the Industrial Engineering Department began the Shipping Department research, the newly created Production and Inventory Control Department issued a carefully calculated list of order quantities and order points for each finished goods item. This list was the result of rigorous application of the most up-to-date inventory control theory coupled with prevailing wisdom concerning the demand patterns for the items. However, the list and the quantities dimensioned for each item precipitated a new consideration.

The past warehousing policy followed the practice of storing all finished goods on pallets. For the slower moving items a single pallet might represent an entire year's supply. A partial pallet may represent the proper inventory amount but poses a warehousing problem since no other pallet may be stacked on top or accessibility is lost. On the other hand, a partially full pallet represents a misuse of potential storage space. Hence, unless a new approach was taken, the alternatives included a partial pallet that resulted in poor space utilization or the more likely situation which occurred when another pallet of dissimilar goods was placed on top, jeopardizing accessibility. Neither alternative was suitable and a rethinking of warehouse policy engendered the following plan of action.

Warehouse changes. With the newly calculated order quantities and order points in hand, an average expected stock level was determined. The results indicated that the most active items would require two or more pallets to be kept in inventory. The area set aside for these was designated Area A. The next less frequently demanded items required a single full pallet. Racks were purchased that would accommodate two pallets. These were set up and designated Area B. Area C consisted of three high racks for partial pallets of the slowest moving items.

The next focus of attention was upon the traffic patterns within and between each area. The goods were arranged in each aisle exactly in the order in which they appeared on an array arranged according to demand in the past six months. The traffic was to move only one way so that aisles could be made narrower. The order picker always started at the point in Area A at which the most active goods were stored and proceeded past the next most active item, etcetera.

A programming change was made so that the items appeared on the order in the same sequence as on the original array (i.e., from the most active to the least active). Prior to this change in the warehouse arrangement, the goods were roughly grouped first by brand, then by size. Under the new arrangement all brands and sizes were mixed. The new arrangement required a learning period for the order pickers. It was felt that after two to three months the adjustment would have been made and that it was reasonable to expect a 20 to 30 percent decrease in shipping costs.

One year later no discernible change in costs had occurred. The only index that reflected a positive change was a slight decrease in shipping errors. At the end of the second year, the impact was the same.

Results of changes. At least two questions might be raised concerning the fact that all the changes that were made in the warehouse yielded no tangible cost reductions. The most immediate question concerns the changes themselves, i.e., perhaps the wrong things were changed. The second question is whether or not changes in the physical layout--

even if it were for the better--could be expected to evoke the kind of behavior modification in the order pickers that was anticipated by management.

The answer to the first question is not definite. A literature search revealed little in the way of criteria. Certain guidelines, however, were available. It is against these that changes made were reflected.

The literature suggests that a great deal of effort has been invested in the development of what is sometimes termed "automated order picking." Chisman reported recently upon such an effort.

> A large textile-manufacturing firm built a warehouse in which several thousand items were inventoried in a quarter of a million square feet of space. In the planning stages of this warehouse, a computer program was sought for:
>
> 1. Routing pickup vehicles through the warehouse to fill their pallets
> 2. Placing the pallets in a particular position on the shipping line
> 3. Loading the orders from the shipping line into a truck so as to minimize the distance traveled to perform these phases of the shipping function[68]
>
> Solution procedure. In order to optimally route order pickers through the warehouse, the author found it was necessary to develop a "fairly accurate" matrix which listed the travel distance between every pair of bins and between every bin and a central point in the shipping area. Optimal assignment of shipping lines was not considered because of the complexity involved and the randomness of both carrier arrivals and loading times.

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[68] J. A. Chisman, "Optimizing the Shipping Function," Industrial Engineering (March 1977), pp. 38-41.

Having identified the routing policies and associated problems the available operations research programs were applied in an attempt to formulate a solution. After a seven-week study the author concluded "That an optimal routing routine, if possible, would be too costly to develop and could not be run on available computer facilities."[69]

Conditions for automated warehouses. Not all attempts at automated facilities have come to the same conclusion. Many have been successful. Sims observes that the most successful systems have generally been favored by the following characteristics:

1. A uniform package size
2. A relatively limited range of package sizes which can be enveloped within one or a few standard common denominator handling units (tote box, pallet, carriers, etc.)
3. Exceptionally high item access requirements
4. Exceptionally high transaction activity levels
5. High value merchandise
6. In-process operations with good control of input-output rates[70]

It would appear that the Shipping Department used for this research might be a likely candidate for the installation of an automated system. The items are uniformly packaged and each order is accumulated on a standardized pallet. In the other criteria, however, the research site does not stand the test. The Sims article[71] further specified that very basic techniques should be used . . .

Where the transaction rate is relatively low (fewer than 200 orders per day) and

Where the merchandise complexity is fairly limited (fewer than

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[69] Ibid., p. 38.

[70] E. Ralph Sims, "Practical Order Picking," Material Handling Engineering (November 1971), p. 52.

[71] Ibid., p. 53.

1,500 items)

These techniques should:

1. Move the man to the point of selection
2. Move the picked merchandise away from the point of selection
3. Provide the man with adequate picking information
4. Keep him in close contact with the merchandise

Consideration of criteria. The research site did, in fact, have fewer than 1,500 items and processed fewer than 200 orders per day in an area of less than 20,000 square feet. However, careful examination of the firm's new layout revealed that it incorporated the techniques suggested by Sims. The one Sims' requirement that was lacking was in-process operations with good control of input-output rates. It was felt that if this control could be achieved it would, of necessity, be based upon some method of work measurement. It was further felt that this quantification of expected performance could be used to evoke the behavior modification discussed in the second question posed above, i.e., the reduction of costs that changed layout had failed to achieve.

These considerations precipitated the writer's research. The following chapters will concentrate upon the research methodology employed to test the hypothesis that was stated at the beginning of the chapter. Also, the results of the research and the implications of the approach to other order picking functions in other organizations will be presented.

CHAPTER IV

METHODOLOGY OF THIS RESEARCH

The purpose of this dissertation is to seek methods for the establishment of performance standards for indirect labor and apply these methods to a specific function (order picking and accumulation) in an existing firm.

To achieve this purpose, the following issues regarding performance criteria are addressed:

1. What measures of productivity for the order picking and accumulation function are to be used?

2. What data sources exist for the selected productivity measures?

3. How are the data sources to be validated?

Since performance standards imply not only output but output within some time constraint the following questions are treated next:

1. What data sources exist to determine the man-hours spent on the order picking and accumulation function during the period under study?

2. How is this data to be validated?

The final phase of the research involves three considerations:

1. The determination of the appropriate methods to be used to determine the order picking and accumulation standards

2. The application of these methods to the data selected

3. Determination of the effectiveness and efficiency of the

methods applied

Order picking and accumulation output. As stated, the research site selected was occupied by eight order pickers who accumulated finished goods from inventory locations to fill retailers' orders. To establish any performance standard, the most fundamental task is to identify output. In the order picking function the most obvious output is orders picked, i.e., an order picker's purpose is to acquire item(s) for shipment. Some orders--particularly small requests--are quickly completed while others take longer. Hence, the number of boxes contained on an order would be a measure of output. The kind of boxes was not a variable since all were the same.

An examination revealed that certain small orders (in terms of the number of boxes ordered) contained as many items requested as large orders. It was therefore reasoned that the number of line items on an order would be a measure of output since each time a line item appeared, a movement to another inventory location was required.

Beginning with these three measures of output, namely (1) number of orders filled, (2) total line items on the orders filled, and (3) total number of boxes picked, the next step is to find data concerning them. The resultant data can be used to construct a model that would test the premise that the time required to pick a group of orders could be accurately predicted if given the following:

1. The number of orders in the group
2. The total number of line items on the orders in the group
3. The total number of boxes called for by the orders on the group

A performance standard should accurately forecast the task's required time. The data required to construct such a performance standard and the methodologies used to obtain and verify such data are the subjects of the next sections.

Data source and validation. Time sheets were the primary data source for past output. It had been standard practice in the firm to require each order picker to fill out a daily time sheet. This listed the hours worked that day; total orders picked; number of boxes picked; time spent out of the department; and the number of line items picked. The foreman of the Shipping Department made no particular attempt to verify the figures presented to him by the order pickers, but he did question anything that in his experience appeared to be unreasonable.

Because of the lack of any rigorous procedure for authentication, an additional analysis was performed for the present study. The bills of lading for all shipments during a 100-week period were audited. These were compared with the time sheets to validate the data from the time sheets prepared by the order pickers. The bills of lading are prepared by the dock foreman and signed by the driver for the common carrier. The comparison showed that:

1. The report of the number of accumulated orders was within 4 percent of those shipped

2. The report of the number of boxes accumulated was within 3 percent of those shipped

3. The report of the number of line items accumulated was within 4 percent of those shipped

Although the shipment data did not exactly match the figures submitted by the order pickers, it was felt that a total error of 4 percent ($\pm$ 2 percent) was acceptable.

Man-hours. The validation of the fourth variable, the number of man-hours worked each day, was performed by an audit of the records of the Payroll Department. Each department, in addition to other data, reported its man-hours and the related employee names. This information was used to determine if an order picker had been reassigned to another department without reporting it.

The same 100-week period used for the validation of the reported number of boxes and line items was chosen. It was found that in some instances an order picker's name appeared in the Shipping Department as well as in some other department. The exact amount of time spent outside the Shipping Department had not, therefore, been correctly reported and constituted a major obstacle to the eventual testing of the performance criteria model since any unexplained variance could be due either to inadequacies of the model or to inaccurate initial data. Since the existing organizational records offered no information that might resolve the inconsistency, both time study and work sampling were utilized.

Introduction to the time study. Three days of continuous time studies were taken. During that period, the number of order pickers varied from six to eight.

Prior to beginning the time study, a separate meeting was held with the foreman. the next day the order pickers were assembled for discussion. The purpose of these meetings was to reduce anxiety since such a reaction could result in abnormal behavior patterns. The purposes of the time study; how the data collected would be used; whether some sort of disciplinary action would result; and similar matters were explained. Although the company had used time study in many other manufacturing departments, none had been made of the order pickers in this or any other job.

The level of concern was so great that the questions posed were recorded in writing. The following day these, along with management's answers, were distributed to the order pickers in a company memorandum. Another meeting was held several days later further to clarify any remaining questions to the order pickers who were not necessarily in favor of the study. After the second meeting they stated that they had no further questions.

Selection of pickers. Having informed the group to be studied of the purposes of the research, the next task was to determine exactly which order pickers should be chosen. Most time study texts address themselves to the question of "choosing an operator," or in this case, an order picker. Niebel, for example, states:

> If more than one operator is performing the work assignment on which the standard is to be established, several things should be taken into consideration in selecting just which operator to use in taking the study. In general, the operator who is average or somewhat above average in performance will give a more satisfactory study than the low-skilled or highly superior operator. The average operator will perform the work consistently and systematically. His pace will tend to be in the approximate range of normal, thereby making it easier for the time study analyst to apply a true performance factor.
>
> Of course, the operator should be completely trained in the method being used and should possess a liking for his work and an interest in doing a good job. He should be familiar with time study procedures and practice, and have confidence in time study methods as well as in the time study analyst. It is desirable that the operator have a cooperative spirit, so that he will follow through willingly with suggestions made by both the foreman and the time study analyst[72]

The criteria suggested by Niebel were rather difficult to apply to the writer's research since there had been no previous performance evaluation. It was therefore impossible to objectively select an "aver-

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[72]Benjamin W. Niebel, Motion and Time Study, 3rd ed. (Homewood, Ill.: Richard D. Irwin), pp. 236-237.

age" order picker and the best alternative was to rely upon the opinion of the foreman. Training might result in employees using a standard method, but there had been neither training nor any particular "proper" method espoused. To make matters more difficult, none of the order pickers had experience or confidence in time study procedures. It was therefore decided that every order picker would be studied. No further attempt was made to apply other criteria such as cooperative spirit or willingness to follow through.

Time study. As stated previously, there were three days of continuous time study. Unlike the traditional time study that features a worker-machine interface which can therefore be taken in a rather well defined geographic area, the order pickers could move through the entire warehouse when filling an order. This would normally require that the time study analyst follow the order picker, but the warehouse studied had a balcony encompassing the entire order picking area which could be utilized for observation. All time studies were taken from this vantage point and each randomly determined order picker was studied for one hour. In addition to allowing the time study analyst to easily switch from one study subject to another, the balcony minimized the probability of the order picker modifying his behavior because of being observed.

The time study made differed from traditional time study methodology in that no attempt was made to pace rate the order picker being studied. The process of pace rating involves the comparison of observed movement with a concept of what a standard work pace should be.

The time study resulted in a determination of each element; a basis for consolidating the elements for the work sampling study; and the determination of primary data required for the calculation of the number of observations required for the work sampling study.

<u>Element classification.</u> It was found that all order pickers' work could be conveniently divided into the elements listed below.

1. Secure a new order
2. Move to correct picking location
3. Pick a carton off storage pallet and place on shipping pallet
4. Band a shipping pallet
5. Prepare a shipping label
6. Affix the shipping label
7. Move completed pallet to the loading dock
8. Deposit completed order with the Traffic Department
9. Out of the Department (other than lunch or break)
10. Confer with the foreman
11. Talk with co-workers
12. Visit rest room

The following verbal descriptions of each element were formulated in order to facilitate observation during the work sampling study:

1. Secure a new order (all movement that occurs from grasping the new order until the first box on that order is touched)

2. Move to a new picking location (all movement that occurs from the point at which the last box of the previous line item is stacked on the shipping pallet and the first box of the next line item is touched)

3. Pick a carton off storage pallet and place on shipping pallet (all movement that occurs from touching the first box on the storage pallet to depositing the last box on the shipping pallet for any given line item)

4. Band a shipping pallet (all movement that occurs from plac-

ing the last box on the shipping pallet to crimping the banding clip)

5. Prepare a shipping label (all movement that occurs from the crimping of the banding clip to moistening of the shipping label)

6. Affix the shipping label (all movement that occurs from the moistening of the label to touching the handle of the pallet mover in anticipation of the movement of the pallet to the loading dock)

7. Move completed pallet to the loading dock (all movement that occurs from touching the pallet mover handle until the handle is released when the shipping pallet is deposited on the loading dock)

8. Deposit completed order with the Traffic Department (all movement that occurs from depositing the previous order on the loading dock until the new order is grasped)

9. Out of the Department (all time during which an order picker is not physically present in the warehouse--other than lunch, break time or in the rest room)

10. Confer with the foreman (all time during which the foreman and order picker are face to face)

11. Talk with co-workers (any face-to-face contact with anyone other than the foreman)

12. Visit rest room (all time involved in the movement to the rest room until the order picker arrives back at the work place)

With the above element descriptions in hand, the work sampling study was undertaken.

Work sampling. The purposes of the work sampling study were to provide a basis for correction of the man-hour data reported on the time sheet and to discover the proportion of the worker's time that constituted avoidable and unavoidable delay. The latter is needed for the final determination of the performance standard.

With regard to the estimated occurrence of each element, the percentages derived from the time study were available. This information was used to determine the number of observations required. The formula suggested for the determination of the number of observations needed for a 95 percent confidence level is:

$$n = \frac{\bar{p}\,(1-\bar{p})}{(\sigma_{\bar{p}})^2}$$

where

$\sigma_{\bar{p}}$ = allowable standard error

$\bar{p}$ = estimated percent occurrence of any element [73]

Careful examination of the formula indicates that for a specific confidence level, the number of observations required increases dramatically as the percentage occurrence of that element decreases. For example, a $\bar{p}$ of 10 percent would require 3,600 observations at a 95 percent confidence level, while a $\bar{p}$ of 1 percent would require 39,600 observations to achieve the same confidence level.

As will be seen, the results of the time study showed that one of the elements occurred only 1 percent of the time. To rigorously confirm through work sampling that percentage of occurrence, 39,600 observations would be required. Since that number of observations was too great for present purposes, the elements that represented common activity

[73]Heiland and Richardson, p. 135.

were combined in accordance with the reasoning below.

The discussion of output earlier in this chapter dimensioned three variables. The three measures of output were:

1. Number of orders filled
2. Total line items on the orders filled
3. Total number of boxes picked

The activity of the order pickers would affect these independent variables, i.e., as the number of orders, line items and boxes increased, the time (dependent variable) required to pick and accumulate the orders would also increase. Since the elements derived from the time study dimensioned what an order picker does, these elements were examined to determine if they could be related to the independent variables previously defined as output. (See the twelve-point listing of elements on pages 71-72.)

Element consolidation. It appeared that the following elements depended upon the number of orders picked, and they occurred either because an order was finished (thereby requiring a new order to be secured) or by the acquisition and processing of a new order.

1. Secure a new order
4. Band a shipping pallet
5. Prepare a shipping label
6. Affix the shipping label
7. Move completed pallet to the loading dock
8. Turn over completed order to the Traffic Department

One could expect that the total times for these elements would be affected by the number of orders processed. Element two, on page 71, "move to a new picking location," is a direct function of the number of line items per order. If an order contained seven items, seven location moves would be required. Element three, "pick a carton off storage pallet and place on shipping pallet," is directly related to the number of cartons the order contains. The more cartons in an order, the more time would be required to pick them off the storage pallet and place them on the shipping pallet.

The remaining elements, on page 71, were:

9. Out of the department (other than lunch or break)
10. Confer with the foreman
11. Talk with co-workers
12. Visit rest room

These normally are unrelated to either the number of orders, boxes or line items. The time out of the Department was of particular interest, however, since it could potentially be used to resolve the discrepancy between payroll data and the man-hours reported in the Shipping Department.

The work sampling study was therefore constructed so that the elements were regrouped and classified as follows:

Designation	Element(s)
O (Order related)	Secure a new order
	Band a shipping pallet
	Prepare a shipping label
	Affix the shipping label
	Move completed pallet to the loading dock
	Turn over completed order to the Traffic Department
L (Line item related)	Move to a new picking location

Designation	Element(s)
C (Carton related)	Pick a carton off storage pallet and place on shipping pallet
A (Absent)	Out of Department (other than lunch or break)
U(Unrelated to the independent variables chosen)	Avoidable delay
P(Personal time)	Visit rest room

With the regrouping of elements, designation A became the smallest percentage element that related to the data to be used for regression analysis. Therefore, designation A governed the number of observations required. Substituting into the equation:

$$n = \frac{\bar{p}(1-\bar{p})}{(\sigma_{\bar{p}})^2}$$

$$n = \frac{(.08)\ (.92)}{(.004)^2}$$

$$n = \frac{.0736}{.000016}$$

$$n = 4{,}600 \text{ observations}$$

To determine the frequency with which observations could be made, a number of test observations were made. A complete tour of the warehouse took approximately nine minutes. Random numbers from Fisher and Yates' statistical tables were used to determine observation times.[74]

Observation routes. Having randomized the periodicity of the observations, the viewing route was next considered. The work sampling technique requires that every event being observed has an equal opportunity to occur. Kay insured random observations by fixing the route but varying the starting points. His study, however, dealt with the observation of activities at fixed work stations.[75] The order pickers, of course, have no fixed work stations and follow a pattern dictated by the orders upon which they are working. It was felt that a fixed route, that would allow each picking aisle to be observed and would be reversed on return, would not bias the results since the order pickers might be checked at any point on the path.

The study was conducted continuously and no work day was skipped for a one-month period. To hold consistent observational bias, one observer--the writer--conducted the entire work sampling. The results of the studies and subsequent data analysis are the subject of the next chapter.

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[74]Ronald A. Fisher and Frank Yates, Statistical Tables for Biological, Agricultural and Medical Research (Darien, Conn.: Hofner Publishing, 1970).

[75]Thomas G. Kay, "Timeless Work Sampling," Industrial Engineering (June 1972), p. 30.

CHAPTER V

RESEARCH FINDINGS AND ANALYSIS

Overview. The research methodologies utilized in this study were time study, work sampling, and regression analysis. The final product was an equation that expressed the relationship between independent variables and time, the dependent variable. The independent variables were:

1. The number of orders shipped
2. The total number of line items contained on the orders shipped
3. The total number of boxes called for by the orders shipped

The results of each research methodology are reported in the order in which the study was performed.

Validation of data. Time sheets, submitted by the personnel performing the order picking and accumulation function, were the primary data source used to initialize the research. The information reported included the totals of hours worked that day; number of orders picked; number of boxes picked; number of line items contained on the orders shipped; and number of hours assigned outside the department.

To verify the data for the independent variables, bills of lading for all shipments during a 100-week period were audited. The audit showed:

1. The report of the number of orders accumulated was within 4 percent of those shipped

2. The report of the number of boxes accumulated was within 3 percent of those shipped

3. The report of the number of line items accumulated was within 4 percent of those shipped

Although the shipment data for the independent variables did not exactly match the figures submitted by the order pickers, it was felt that a total error of 4 percent ($\pm$ 2 percent) was acceptable.

The validation of the dependent variable, the number of man-hours worked each day, was performed by an audit of the records of the Payroll Department. The same 100-week period was chosen as that used for the validation of the reported number of orders, boxes and line items. The data source used was a daily report prepared by the department head that listed the employee's name, the time that the employee was assigned to the Shipping Department, and the time the employee was assigned outside the Shipping Department. It was found that in some instances an order picker's name appeared in the Shipping Department as well as in some other department. It was concluded that time study and work sampling was needed to determine the amount of time spent outside the Shipping Department.

<u>Time study</u>. Three days of continuous time studies were taken. During this period, the number of order pickers varied from six to eight.

The purposes of the time studies were to:

1. Determine the accuracy of the data reported as the man-hours assigned outside the Shipping Department

2. Determine whether there exist activities in the normal regimen of order picker activity that would appear to be unrelated to the three independent variables described above

3. Serve as a basis for partitioning into observable categories the order picking activities for purposes of the work sampling study and to calculate the sample size required for work sampling

Time study results. The three-day time study yielded the following:

Table I

Percent of Time	Element Description
3.0	Prepare a shipping label
3.0	Band a pallet
2.0	Secure a new order
4.0	Move completed order to the loading dock
1.0	Affix the shipping label
2.0	Turn over completed order to the Traffic Department
31.0	Move to a new picking location
35.0	Pick a carton off storage pallet and place on shipping pallet
8.0	Out of department (other than lunch or break)
2.0	Confer with foreman
5.0	Talk with co-workers
4.0	Visit rest room
100.0	

The time observed outside the department constituted 8 percent of the total observed time. This finding will be compared with the more comprehensive results of the work sampling study.

Element simplification. The partitioning and combining elements prior to the work sampling were done as follows (see Table II, page 82):

The major consideration in the determination of the number of observations required was the percentage of time that order pickers were assigned outside the department. This must be accurately determined in order to validate and/or correct the data to be used for the dependent variable prior to the regression analysis.

The number of observations was so calculated that a precision interval of plus or minus 10 percent of the true population value was assured at a confidence level of 95 percent. For a $\bar{p}$ of 8 percent the required number of observations is 4,600.

Work sampling. The work sampling study was conducted without interruption for a one-month period. To hold consistent observational bias, one observer conducted the entire work sampling. All eight order pickers were observed by following a fixed route. The frequency of observations, however, had been randomized.

The purpose of the work sampling was to accurately determine the time the order pickers were assigned outside the Shipping Department. The results of this finding were used to modify the time that had been reported as having been spent outside the department. This modification was necessary to resolve the discrepancy discovered during the validation study of the data to be used in the regression analysis.

Work sampling results. The results of 4,600 work sampling observations were (see Table III, page 83):

Table II

Designation	Element(s)	Percent of Time
O (Order related)	Secure a new order	2.0
	Band a shipping pallet	3.0
	Prepare a shipping label	3.0
	Affix the shipping label	1.0
	Move completed pallet to the loading dock	4.0
	Turn over completed order to the Traffic Department	2.0
		15.0
L (Line item related)	Move to a new picking location	31.0
C (Carton related)	Pick a carton off storage pallet and place on shipping pallet	35.0
A (Absent)	Out of the Department (Other than lunch or break)	8.0
U (Unrelated to the independent variables chosen and avoidable)	Confer with Foreman	2.0
	Talk with co-workers	5.0
		7.0
P (Personal time)	Visit rest room	4.0
		100.0

Table III

Classification	P (percent occurrence)	$\sigma_{\bar{p}}$
O (Order related)	0.143	± .006
L (Line item related)	0.286	± .007
C (Carton related)	0.332	± .007
A (Absent)	0.114	± .004
U (Unrelated to the independent variables chosen)	0.084	± .005
P (Personal time)	0.041	± .004
	1.000	

The A designation was found to be 11 rather than the 8 percent of the time used to calculate the number of observations required. This finding indicates that a recalculation need be performed to assure that a sufficient number of observations have been taken. As in the previous calculation, the sample was so designed that a precision interval of plus or minus 10 percent of the true population value was assured at a confidence level of 95 percent. The number of observations required upon the assumption that designation A is in fact 11 percent is 3,075. The study therefore exceeded the number of observations required.

The resolution of the discrepancy in the data to be used for the dependent variable was accomplished by reducing the time clock hours for each picker by 11.4 percent for the 100-week period under study.

Regression model I. The purpose of the regression analysis is to determine the nature of the relationship between the independent variables (number of orders shipped, number of line items contained on the orders shipped, and the number of boxes shipped) under study and the working time reported by the order pickers.

Using data reported by the order pickers (having corrected for the time reported outside the department), a multi-variate regression analysis was performed. The definitions of the variables follow:

Y = time (hours)

X_1 = number of orders shipped

X_2 = number of line items contained on orders shipped

X_3 = number of boxes shipped

The regression equation that resulted from the analysis is:

$$Y = 43.71969 + 0.41222X_1 + 0.43634X_2 + 0.29835X_3$$

where

Multiple Correlation Coefficient	0.671
F-value for the Analysis of Variance	44.710

and

Variable	Regression Coefficient	Standard Error of Regression Coefficient	Computed F-value
X_1	0.41222	0.12236	16.687
X_2	0.43634	0.10681	50.512
X_3	0.29835	0.04198	11.350

Since the number of orders, line items, and boxes shipped are related not only to the amount of time it requires to ship them, but also one to another, multicollinearity was considered.

<u>Multicollinearity</u>. Multicollinearity refers to that situation in which some or all of the independent variables are very highly in-

tercorrelated. Multicollinearity can cause difficulties with respect to the following:

> 1. If at least one of the independent variables is a perfect linear function of one or more other independent variables in the equation, the coefficients may not be uniquely determined
> 2. Estimates of the regression coefficients from sample to sample may fluctuate markedly
> 3. One of the uses of multiple regression as an interpretive tool is to evaluate the relative importance of the independent variables. The situation is somewhat paradoxical, however. The more strongly correlated the independent variables are (excluding, of course, extreme multicollinearity which prevents the coefficients from being calculated at all), the greater the need for controlling the confounding effects. However, the greater the intercorrelation of the independent variables, the less the reliability of the relative importance indicated by the partial regression coefficients.[76]

The correlation matrix indicates that there is a higher degree of correlation between variables one and two than between any other combination of independent variables. The issue then becomes, which variable is to be dropped, one or two?

Consideration three above was of particular concern. Of the independent variables considered in the regression model I, it is safe to assume that, as the number of orders increase, so also would the number of boxes and the number of line items. According to Green and Tull:

> There are three basic procedures for dealing with multicollinearity; (a) ignore it; (b) delete one or more of the "offending" predictors; and (c) transform the set of predictor variables into a new set of predictor variable combinations that are mutually uncorrelated.[77]

Correlation matrix. Alternative two was pursued, i.e., an "of-

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[76]N. H. Nie, C. H. Hull, J. Jenkins, K. Steinbrenner, D. H. Bent, Statistical Package for the Social Sciences, 2nd (McGraw-Hill Book Company; New York 1970).

[77]P. E. Green and D. S. Tull, Research for Marketing Decisions, 3rd. ed. (Englewood Cliffs, New Jersey: Prentice-Hall, Inc. 1975), p. 479.

fending" predictor was deleted. To arrive at a decision as to which independent variable to delete, a correlation matrix was calculated. The matrix is designed to demonstrate how closely the independent variables are correlated, one with another. For purposes of this calculation, the variables were defined as follow:

Variable	Definition
1	Number of orders
2	Number of line items
3	Number of boxes
4	Man-hours

The correlation matrix that resulted from the calculations was:

Variable	Variable 1	Variable 2	Variable 3	Variable 4
1	1.00000	0.58984	0.01319	0.42404
2	0.58984	1.00000	0.15548	0.50528
3	0.01319	0.15548	1.00000	0.46913
4	0.42404	0.50528	0.46913	1.00000

Independent variables for regression model II. It was decided to drop orders shipped. The reasoning involved in the decision was (1) each order shipped demanded the same amount of time in order related activities; and (2) it made no difference what was on the order when only the following elements were considered:

Designation	Elements
O (Order related)	Secure a new order
	Band a shipping pallet
	Prepare a shipping label

Move completed pallet to the loading dock

Turn over completed order to the Traffic Department

On the other hand, each time a line item appeared on an order a movement to a new warehouse location was dictated. If an order were given to the order picker, the time involved for order-related activities could be predicted from time study alone. It remains the function of regression analysis to explain the variance on time required to ship that results from considering the line items shipped.

Regression model II. A second multi-variate regression analysis was calculated. The variables were reduced by one and defined as follow:

Y = time (hours)

X_1 = number of line items contained on orders shipped

X_2 = number of boxes shipped

The regression equation is:

$$Y = 50.84199 + 0.65047X_1 + 0.28443X_2$$

where

Multiple Correlation Coefficient 0.642

F-value for the Analysis of Variance 57.76792

and

Variable	Regression Coefficient	Standard Error of Regression Coefficient	Computed F-value
X_1	0.65047	0.08850	54.027
X_2	0.28443	0.04306	43.622

The net effect of dropping the variable, number of orders shipped, was to slightly reduce the variance explained by the regression equation and to increase the F-values for the overall analysis of variance and for the regression coefficients. The regression equation of model II explains approximately 40 percent of the variance but at a greater significance level for both the overall equation and the variable coefficients. It can be concluded that part of the variance explained by Model I was due to the correlation that existed between the number of orders and the number of line items.

Non-linearity. Regression analysis assumes that the underlying relationships among the variables are linear and additive. It is possible that a linear relationship for the data being researched is inappropriate. To test for non-linearity, successive powers of the independent variables were introduced into the Model II regression equation along with the original variables. The purpose of this test was to determine if the introduction of polynomial terms resulted in significant increases in the variance explained by the equation (R^2). Since the ultimate goal was to obtain the simplest equation that adequately describes the relationship, the polynomial terms are introduced in steps. At each step the increases in R^2 are assessed so as to find the point at which no substantial improvement of fit is obtained.

Test for non-linearity. The independent variables used in the test for non-linearity follow: (see Table IV, page 89);

The combination of variables that best fit the data were X_3 and X_2. This combination resulted in the following values:

Multiple Correlation Coefficient	0.67965
F-value for the Analysis of Variance	70.82426

Table IV

Variable	Definition
X_1	Number of line items
X_2	Number of boxes
X_3	Number of line items squared
X_4	Square root of the number of line items
X_5	Number of boxes squared
X_6	Square root of the number of boxes

Variable	Regression Coefficient	Standard Error of Regression Coefficient	Computed F-value
X_3	0.00792	0.00092	74.414
X_2	0.26869	0.04138	42.161

This resulted in the regression equation:

$$Y = 64.69768 + 0.00792X_3 + 0.26869X_2$$

Variance explained by this equation (R^2) is 46.2 percent. The introduction of any other variables was pursued but rejected because of the reintroduction of multicollinearity and the minimal impact upon R^2.

Therefore, the non-linear regression equation that best explains the variance in the data researched and serves as the model for the determination of order picking standards is:

$$Y = 64.69768 + 0.00792X_3 + 0.26869X_2$$

where X_3 = number of line items squared

X_2 = number of boxes shipped

Y = time (hours)

Implications of the final regression equation. The equation indicates an intercept on the Y axis is 64.69768 hours. Rigorously interpreted, this statistic would indicate that if no orders were processed, a fixed cost of 64 plus hours would be incurred. One explanation for this is the curvi-linear nature of the model. The regression equation is built upon data that fits only the middle range of the curve. To extrapolate it in the lower range yields an intercept on the Y axis that is pragmatically untenable.

The same danger lies in extrapolating the curve past the original data at its upper end. If the regression equation were used as the basis for incentive payment, an upper limit at the border of the curve bounded by existing data would need to be imposed as an "a priori" condition. The reason is the exponential impact of the line items. As work load increased past the portion of the curve bounded by existing data earnings could become unreasonably and inappropriately high.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Conceptual basis of the model. The purpose of this dissertation was to seek methods for the establishment of performance standards for indirect labor tasks. Various methods were applied to a specific function (order picking and accumulation) in an existing firm. As a result of the application of these methods, a quantitative model of the order picking and accumulation function was developed.

The ultimate value of such a model would be that it could be used to determine performance standards for the order picking and accumulation function. Such standards are the base upon which to plan manpower requirements, quantify measures of performance and provide feedback concerning how effectively the order picking and accumulation functions were being performed.

The role of performance standards in organizational theory. Much controversy exists in the literature today concerning the root causes of unsatisfactory employee performance. At least three fundamental theoretical positions underlie the research and writing in this area. The first springs from the human relations movement that emphasizes physiological and psychological well-being of the employee. Following the investigations at Western Electric, a great number of studies were conducted which attempted to identify productivity as correlates of high and low job satisfaction. This interest in job satisfaction developed not so much from charitable considerations but from the continued desire to increase human productivity. Simply stated, this opportunity for improvement hinges on the belief that the degree of job satisfaction felt by the employee is positively related to the employee's performance. The popular version of this tenet is "a happy worker is a productive worker." At the theoretical level, Vroom's valence-force model is an example of the theoretical support for the satisfaction-causes-performance case.[78]

Performance causes satisfaction. More recently, the work of Porter and Lawler has proposed that job satisfaction is not the cause of performance but rather the effect.[79] They propose that satisfaction is a function of performance related rewards. Further research by Bowen and Siegel,[80] and Greene[81] tends to support the Porter and Lawler hypothesis. In both studies, relatively strong correlations were found between performance and satisfaction expressed later. These were significantly higher than the correlations between satisfaction and performance which occurred during the subsequent period.

More recent research reinforces the theoretical position of Porter and Lawler but considers both satisfaction and performance to be

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[78]Victor H. Vroom, Work and Motivation (New York: John Wiley & Sons, Inc., 1964) p. 136.

[79]Lyman W. Porter and Edward E. Lawler III, Managerial Attitudes and Performance (Homewood, Ill.: Richard D. Irwin, Inc., 1968).

[80]Donald Bowen and Jacob P. Siegel, "The Relationship Between Satisfaction and Performance; the Question of Causality," paper presented at the annual meeting of American Psychology Association, Miami Beach, September, 1970.

[81]Charles N. Greene, "A Causal Interpretation of Relationship Among Pay, Performance and Satisfaction," paper presented at annual meeting of the Midwest Psychology Association, Cleveland, Ohio, May, 1972.

functions of rewards. In this view, rewards cause satisfaction, and rewards that are based on current performance cause subsequent performance. In other words, merit pay was identified as a cause of satisfaction and was found to be a significantly more frequent source of satisfaction than dissatisfaction. The results of this study further revealed equally significant relationships between (1) merit pay and subsequent performance and (2) current performance and subsequent merit pay.[82]

Implications for management. These findings have several important implications. For the manager who desires to enhance the satisfaction of subordinates (perhaps for the purpose of reducing turnover), the implication of the finding that rewards cause satisfaction is self evident. If, on the other hand, the manager's interest in a subordinate's satisfaction arises from a desire to increase performance, the consistent rejection of the satisfaction-cause-performance proposition has an equally clear implication, i.e., increasing subordinates' satisfaction may have no effect on performance.

Performance standards are critical. The above arguments pursue what Greene[83] defines as the three definitive theoretical positions that address the issue of worker satisfaction and productivity. It is difficult to conjecture whether history will prove any of these to be correct or serve to introduce a new idea for future generations to research. The critical point is that each approach assumes that performance is mea-

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[82]David J. Cherrington, H. Joseph Reitz, and William E. Scott, Jr., "Effects of Contingent and Non-contingent Reward on the Relationship Between Satisfaction and Task Performance," Journal of Applied Psychology, LV (December, 1971) pp. 531-36.

[83]Charles Greene, "The Satisfaction-Performance Controversy," Business Horizons, 15 (October, 1972).

surable and that performance standards can be established.

Greene mentions the difficulties involved in appraisal (based upon performance criteria) when he discusses the findings of the satisfaction-performance research.

> If these implications are to be considered as prescriptions for managerial behavior, one is tempted at this point to conclude that all a manager need do in order to increase his subordinates' performance is to accurately appraise their work and reward them accordingly. However, given limited resources for rewards and knowledge of appraisal techniques, it is all too apparent that the manager's task is not easy.

Although this research is not specifically designed to make the shipping manager's job easy, it does provide the basis for determining order picking and accumulation standards. As such, it not only addresses the problem of productivity in an area that had been previously unreported, and affects the job satisfaction of order pickers. The following considerations are involved in using the regression model described earlier as the basis for performance standards in order picking and accumulation function.

Determination of performance standards. As stated earlier, this dissertation was designed to:

1. Determine an appropriate methodology for establishing performance standards for non-repetitive tasks

2. Apply this methodology to the order picking and accumulation function in an existing environment

3. Demonstrate the relative efficiency of the method applied as contrasted with a traditional approach

The methods utilized have been discussed in Chapter IV; the application of the methods and the results appear in Chapter V. What remains is to demonstrate the effectiveness and efficiency of performance standards that are based upon regression analysis.

Effectiveness of performance standards based upon regression analysis. When regression analysis is used in the physical sciences, the primary consideration in appraising a regression equation is how well it explains variance in the data. The reason for this emphasis in the physical sciences is that cause and effect are predictable. At a given temperature and pressure a certain reaction is forthcoming, assuming that the proper predictor variables have been included.

This comfortable assumption does not necessarily hold for data that is affected by behavioral considerations. In the case under study, the non-linear regression equation

$$Y = 64.69768 + 0.0079X_1^2 + 0.26869X_2$$

explained 46.2 percent of the variance in the data. The variance left unexplained may be due, as in the case of the physical sciences, to the fact that other predictor variables were ignored. Or it may be, unlike the case of the physical sciences, that given a certain number of line items and boxes to ship, the order pickers do not always react in the same way. It must be remembered that the data used in the regression analysis came from an environment in which no performance standards were present. No expected work pace had been established and all kinds of environmental factors that are both endogenous and exogenous to the work itself could affect work pace. The crew may be understaffed or overstaffed; reduced work in the future and slow down may be expected; or an unanswered grievance may be pending. These and other considerations could have a dramatic effect upon the time expended.

The variance left unexplained by the regression equation may therefore be variance in human behavior rather than the residual variance left unexplained by not considering the proper predictor variables.

Decision criteria. The literature offers no assistance in defining the "goodness of fit" that is required for a regression equation to be effectively used as a basis for performance standards. From an empirical point of view Abranovic decided that a correlation coefficient of 0.7 indicated a favorable response estimator. Having completed the study and installed time standards, the same researcher concluded: "the results [of the regression analysis] provide the basis for establishing a work incentive system."[84] In Abranovic's study a regression equation that explained 49 percent of the variance (R^2) was deemed adequate not only for establishing performance standards but also as the basis for an incentive system.

The question as to how much unexplained variance is tolerable in the regression equation is the central issue that must be decided before the regression equation can be used as the basis for performance standards. Since the literature offers little by way of guidelines, the practitioner will need to rely upon subjective analysis in deciding whether the regression equation, and particularly the variance it explains, is adequate as a basis for standards. One tool that can be of assistance is called rating.

Rating. Rating is the procedure commonly used with stop-watch time study techniques. It is a technique for equitably determining the time required to perform a task by the normal operator after the observed values of the operation under study have been recorded. A "nor-

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[84]Abranovic, p. 577.

mal" operator is defined as (1) a qualified, thoroughly experienced operator, (2) working under conditions as they customarily prevail at the work station, (3) at a pace that is neither fast nor slow, but representative of average.[85]

The rating technique evolved as a very necessary part of time study. Having time-studied a person and carefully calculated the time each element of a task took, the question arose, should this time be established as a standard? This question raises other issues that have to do with the pace at which a person is working. It became obvious that some subjective technique that allowed the time study person to evaluate or rate the work pace need be developed. This technique is called rating.

A parallel exists between the dilemma of the time study person who uses carefully timed observations to arrive at both elemental times and the total time to do a job, and the researcher who uses regression analysis to construct a model that uses time as the dependent variable. The time study person must decide whether the time values that were observed vary significantly from the normal work pace. The researcher must determine whether the variance left unexplained by the regression analysis is too great to allow it to be used as a standard. Rating can aid in the researcher's decision just as it aids the time study person.

Rating applied with work sampling. Rated work sampling is performed in the same manner as conventional work sampling but has the added feature that each observation has a pace rating. The pace rating is assigned to the work sampling observation just as it is assigned to an

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[85]B. W. Niebel, p. 265.

element in time study. In work sampling an instantaneous observation is made, and the analyst decides if the worker is productive or idle. Or, if it is detailed work sampling, the analyst would indicate the element the worker was performing and show a pace rating. Not every observation needs to be rated.[86]

If there exists a wide variance in the rating upon summarizing the rated activities, it is safe to assume that this may be part of the variance left unexplained by the regression equation. On the other hand, if the ratings are fairly consistent over all elements performed by all operators (order pickers), one would be more reluctant to use a regression equation that leaves a large part of the variance in the data unexplained as a basis for performance standards. This is because variation in behavior is not apparent and could not be said to contribute in major part to the unexplained regression variance.

In the research under discussion, the ratings varied from 50 percent to 90 percent. This variance in rating of 40 percent approaches the variance left unexplained by the regression equation. It was concluded that at least part of the variance left unexplained by the regression equation was due to variance in order picker performance.

Performance standard. To determine the performance standard, the rating must be applied to the regression equation. In some cases the ratings are averaged.[87] If extremes are present, especially on the low side, a more conservative approach would be to use the median as a measure of central tendency. In the research reported here, the median was

[86]Charles Travis, "Trouble-Shoot with Rated Work Sampling," Industrial Engineering (September 1970), pp. 19-23.

[87]Travis, p. 20.

most appropriate since no one "normal" operator (order picker) was studied. All were studied. The median rating was .75 percent.

Since the rating was determined to be 75 percent, the performance standard was:

$$Y = .75\ (64.69768 + 0.00792X_3^2 + 0.26869X_2)$$

If great variation had been found in the ratings, a more rigorous approach would have been to apply the ratings to the data prior to the regression analysis. Since the ratings showed little variation, the regression analysis was performed and the rating applied to the regression equation. The point of concern is the impact of the rating upon the residual.

Efficiency of performance standards based upon regression analysis. In a previous section the number of line studies required to determine traditional standards in the shipping department being researched was calculated. It was determined that 980,700 time studies would be needed.

The combined time study work sampling regression analysis approach described here required six man-months. This approach, however, presupposed the existence of data pertaining to the required independent variables.

To aid in comparing the relative initial cost for initializing the performance standard program, one might consider that a prominent practitioner states that "a top notch time study person cannot set more than fifteen standards per day, and this is the outside limit."[88] This would mean that in excess of 65,000 man-days of time study would be required to

[88]Clifford Sellie, speech presented at the 1970 Industrial Management Annual Clinic. Reprints available from Standards International, Inc. (Chicago, Illinois).

establish a standards program based only upon time study techniques.

The regression equation would require that one calculation per week be made to determine the performance of the order pickers relative to the performance standard.

The traditional time approach would require that 980,000 standards be stored and be capable of being randomly accessed. In addition it would require that an information system provide each material location from which a movement was begun and the material location at which the movement ended. An individual calculation would then be required for each such movement in order to determine the performance against standard.

Maintenance of the performance standard system. Perhaps the greatest contrast in relative efficiency occurs in maintenance costs.

In the traditional time study system, each change made in the work environment requires at least one new time study. Many reasons could cause this effort, such as a stock overrun or stock out, etcetera.

This is not the case with the approach utilized in this research. The data used for the regression equation were taken from a period in which any environmental variation that might happen was allowed to happen. There was no attempt to "normalize" the environment to conform to the predictability required by traditional time study. Change is therefore inherent in the model. No change, other than a dramatic re-layout of all item locations, would require another study to be made.

Conclusions. Regression analysis provides an efficient and effective means for determining performance standards for the order picking and accumulation functions. The major constraints to more widespread utilization of the methods used in this research are (1) the existence of data pertinent to the proper predictor variables, and (2) the lack of guidelines with which to determine the "goodness of fit" required for performance standards application.

The first limitation is environmentally determined. The rating approach suggested by the writer provides a valuable approach to aid in deciding whether or not to use a given regression equation as the basis for determination of standards for indirect work.

In the final analysis, however, many more applications must be undertaken before discrete criteria are evolved. The subject is worthy of further research, not only because of the large portion of work activity that is classified as indirect, but also because of the prominent position that performance standards occupy in management theory.

FILE NONAME (CREATION DATE = [illegible]7/07/77)

VARIABLE	MEAN	STANDARD DEV	CASES
V1	3[illegible].[illegible]076	7.4846	168
V2	39.[illegible]587	6.6786	168
V3	7[illegible].34[illegible]	17.6343	168
V4	96.7757	12.7074	168
V2SQ	1603.5893	[illegible]03.6335	168
V2RT	6.2775	[illegible].6741	168
V3SQ	5263.[illegible]14	2746.9696	168
V3RT	[illegible].3152	1.0975	168

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FILE NONAME (CREATION DATE = 07/07/77)

CORRELATION COEFFICIENTS

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

	V1	V2	V3	V4	V2SQ	V2RT	V3SQ	V3RT
V1	1.00000	0.58982	0.01318	0.42408	0.57807	0.58509	0.03946	-0.00412
V2	0.58982	1.00000	0.15547	0.50631	0.97064	0.99317	0.17647	0.13840
V3	0.01318	0.15547	1.00000	0.46825	0.18196	0.14390	0.97172	0.98672
V4	0.42408	0.50631	0.46825	1.00000	0.56959	0.47124	0.47515	0.43636
V2SQ	0.57807	0.97064	0.18196	0.56959	1.00000	0.93694	0.21644	0.15802
V2RT	0.58509	0.99317	0.14390	0.47124	0.93694	1.00000	0.15863	0.12991
V3SQ	0.03946	0.17647	0.97172	0.47515	0.21644	0.15863	1.00000	0.92373
V3RT	-0.00412	0.13840	0.98672	0.43636	0.15802	0.12991	0.92373	1.00000

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* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE.. V4

VARIABLE(S) ENTERED ON STEP NUMBER 1.. V2

MULTIPLE R	0.50631
R SQUARE	0.25635
ADJUSTED R SQUARE	0.25187
STANDARD ERROR	10.99124

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
REGRESSION	1.	6912.85846	6912.85846	57.22215
RESIDUAL	166.	20054.02481	120.80738	

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2	0.74134	0.50631	0.09800	57.222
(CONSTANT)	67.22659			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V1	0.19238	0.18015	0.65211	5.534
V3	0.39918	0.45727	0.97583	43.622

* *

VARIABLE(S) ENTERED ON STEP NUMBER 2.. V3

MULTIPLE R	0.64175
R SQUARE	0.41184
ADJUSTED R SQUARE	0.40471
STANDARD ERROR	9.80440

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
REGRESSION	2.	11106.03703	5553.01852	57.76792
RESIDUAL	165.	15860.84624	96.12634	

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2	0.65047	0.44425	0.08850	54.027
V3	0.28443	0.39918	0.04306	43.622
(CONSTANT)	5[illegible].84199			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V1	0.24280	0.25441	0.64579	11.350

FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE.. V4

VARIABLE(S) ENTERED ON STEP NUMBER 3.. V1

MULTIPLE R	0.67075	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
R SQUARE	0.44991	REGRESSION	3.	12132.65186	4044.21729	44.71089
ADJUSTED R SQUARE	0.43985	RESIDUAL	164.	14834.23141	90.45263	
STANDARD ERROR	9.51066					

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2	0.43634	0.29860	0.10681	16.687
V3	0.29835	0.41872	0.04198	50.512
V1	0.41222	0.24280	0.12236	11.350
(CONSTANT)	43.71969			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F

MAXIMUM STEP REACHED

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FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE.. V4

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
V2	0.50631	0.25635	0.25635	0.50631	0.43634	0.29800
V3	0.64175	0.41184	0.15549	0.46825	0.29835	0.41872
V1	0.67075	0.44991	0.03807	0.42408	0.41222	0.24280
(CONSTANT)					43.71969	

FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 2

DEPENDENT VARIABLE.. V4

VARIABLE(S) ENTERED ON STEP NUMBER 1.. V2

MULTIPLE R	0.50631
R SQUARE	0.25635
ADJUSTED R SQUARE	0.25187
STANDARD ERROR	10.99124

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
REGRESSION	1.	6912.85846	6912.85846	57.22215
RESIDUAL	166.	20054.02481	120.80738	

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2	0.74134	0.50631	0.09800	57.222
(CONSTANT)	67.22659			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V3	0.39918	0.45727	0.97583	43.622

* *

VARIABLE(S) ENTERED ON STEP NUMBER 2.. V3

MULTIPLE R	0.64175
R SQUARE	0.41184
ADJUSTED R SQUARE	0.40471
STANDARD ERROR	9.80440

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
REGRESSION	2.	11106.03703	5553.01852	57.76792
RESIDUAL	165.	15860.84624	96.12634	

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2	0.65047	0.44425	0.08850	54.027
V3	0.28443	0.39918	0.04306	43.622
(CONSTANT)	50.84199			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F

MAXIMUM STEP REACHED

FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 2

DEPENDENT VARIABLE.. V4

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
V2	0.50631	0.25635	0.25635	0.50631	0.65047	0.44425
V3	0.64175	0.41184	0.15549	0.46825	0.28443	0.39918
(CONSTANT)					50.84199	

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FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 3

DEPENDENT VARIABLE.. V4

VARIABLE(S) ENTERED ON STEP NUMBER 1.. V2SQ

MULTIPLE R	0.56959	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
R SQUARE	0.32443	REGRESSION	1.	8748.97069	8748.97069	79.71984
ADJUSTED R SQUARE	0.32036	RESIDUAL	166.	18217.91258	109.74646	
STANDARD ERROR	10.47599					

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2SQ	0.00901	0.56959	0.00101	79.720
(CONSTANT)	51.79233			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V2	-0.80482	-0.23552	0.05785	9.690
V3	0.37709	0.45113	0.96689	42.161
V2RT	-0.51115	-0.21734	0.12214	8.181
V3SQ	0.36916	0.43849	0.95315	39.277
V3RT	0.35523	0.42676	0.97503	36.741

* *

VARIABLE(S) ENTERED ON STEP NUMBER 2.. V3

MULTIPLE R	0.67965	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
R SQUARE	0.46192	REGRESSION	2.	12456.66891	6228.33446	70.82426
ADJUSTED R SQUARE	0.45540	RESIDUAL	165.	14510.21436	87.94069	
STANDARD ERROR	9.37767					

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2SQ	0.0[illegible]792	0.50098	0.00[illegible]92	74.414
V3	0.26869	0.37709	0.04138	42.161
(CONSTANT)	64.69763			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V2	-0.67239	-0.21960	0.05739	8.309
V2RT	-0.43167	-0.20505	0.12141	7.198
V3SQ	0.00533	0.00169	0.05414	0.000
V3RT	-0.57482	-0.12611	0.02590	2.650

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FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * *   VARIABLE LIST 1
REGRESSION LIST 3

DEPENDENT VARIABLE.. V4

VARIABLE(S) ENTERED ON STEP NUMBER 3.. V2

		ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
MULTIPLE R	0.69848	REGRESSION	3.	13156.38242	4385.46081	52.07744
R SQUARE	0.48787	RESIDUAL	164.	13810.50085	84.21037	
ADJUSTED R SQUARE	0.47850					
STANDARD ERROR	9.17662					

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2SQ	0.01823	1.15630	0.00371	24.348
V3	0.25821	0.36239	0.04066	40.335
V2	-0.98452	-0.67239	0.34154	8.309
(CONSTANT)	37.43787			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V2RT	3.83241	0.16197	0.00091	4.392
V3SQ	-0.16845	-0.05321	0.05109	0.463
V3RT	-0.43012	-0.09556	0.02528	1.502

* *

VARIABLE(S) ENTERED ON STEP NUMBER 4.. V3RT

		ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
MULTIPLE R	0.70182	REGRESSION	4.	13282.49466	3320.62367	39.55322
R SQUARE	0.49255	RESIDUAL	163.	13684.38861	83.95330	
ADJUSTED R SQUARE	0.48010					
STANDARD ERROR	9.16260					

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2SQ	0.01744	1.10311	0.00376	21.488
V3	0.56255	0.78952	0.25161	4.999
V2	-0.91900	-0.62764	0.34519	7.088
V3RT	-4.98020	-0.43012	4.06338	1.502
(CONSTANT)	106.22939			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V2RT	3.65129	0.15433	0.00091	3.953
V3SQ	-2.68766	-0.34694	0.00846	22.168

FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 3

DEPENDENT VARIABLE.. V4

VARIABLE(S) ENTERED ON STEP NUMBER 5.. V3SQ

MULTIPLE R	0.74406
R SQUARE	0.55363
ADJUSTED R SQUARE	0.53985
STANDARD ERROR	8.61996

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
REGRESSION	5.	14929.68009	2985.93602	40.18555
RESIDUAL	162.	12037.20318	74.30372	

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
V2SQ	0.02191	1.38543	0.00366	35.733
V3	4.86925	6.83377	0.94483	26.559
V2	-1.29438	-0.88461	0.33439	14.984
V3RT	-45.39506	-3.92058	9.39646	23.339
V3SQ	-0.01243	-2.68766	0.00264	22.168
(CONSTANT)	212.33616			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F
V2RT	3.80873	0.17162	0.00091	4.886

F-LEVEL OR TOLERANCE-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

FILE NONAME (CREATION DATE = 07/07/77)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 3

DEPENDENT VARIABLE.. V4

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
V2SQ	0.56959	0.32443	0.32443	0.56959	0.02191	1.38543
V3	0.67965	0.46192	0.13749	0.46825	4.86925	6.83377
V2	0.69848	0.48787	0.02595	0.50631	-1.29438	-0.88401
V3RT	0.70182	0.49255	0.00468	0.43636	-45.39506	-3.92058
V3SQ	0.74405	0.55363	0.06108	0.47515	-0.01243	-2.68766
(CONSTANT)					212.33616	

```
DATA TRANSFORMATION DONE UP TO THIS POINT..

      NO OF TRANSFORMATIONS                4
      NO OF RECODE VALUES                  0
      NO OF ARITHM. OR LOG. OPERATIONS     4
THE AMOUNT OF TRANSPACE REQUIRED IS      400 BYTES


         SCATTERGRAM    V4 WITH V1 TO V3
         STATISTICS     ALL


**** GIVEN WORKSPACE ALLOWS FOR   2623 CASES FOR SCATTERGRAM PROBLEM *****
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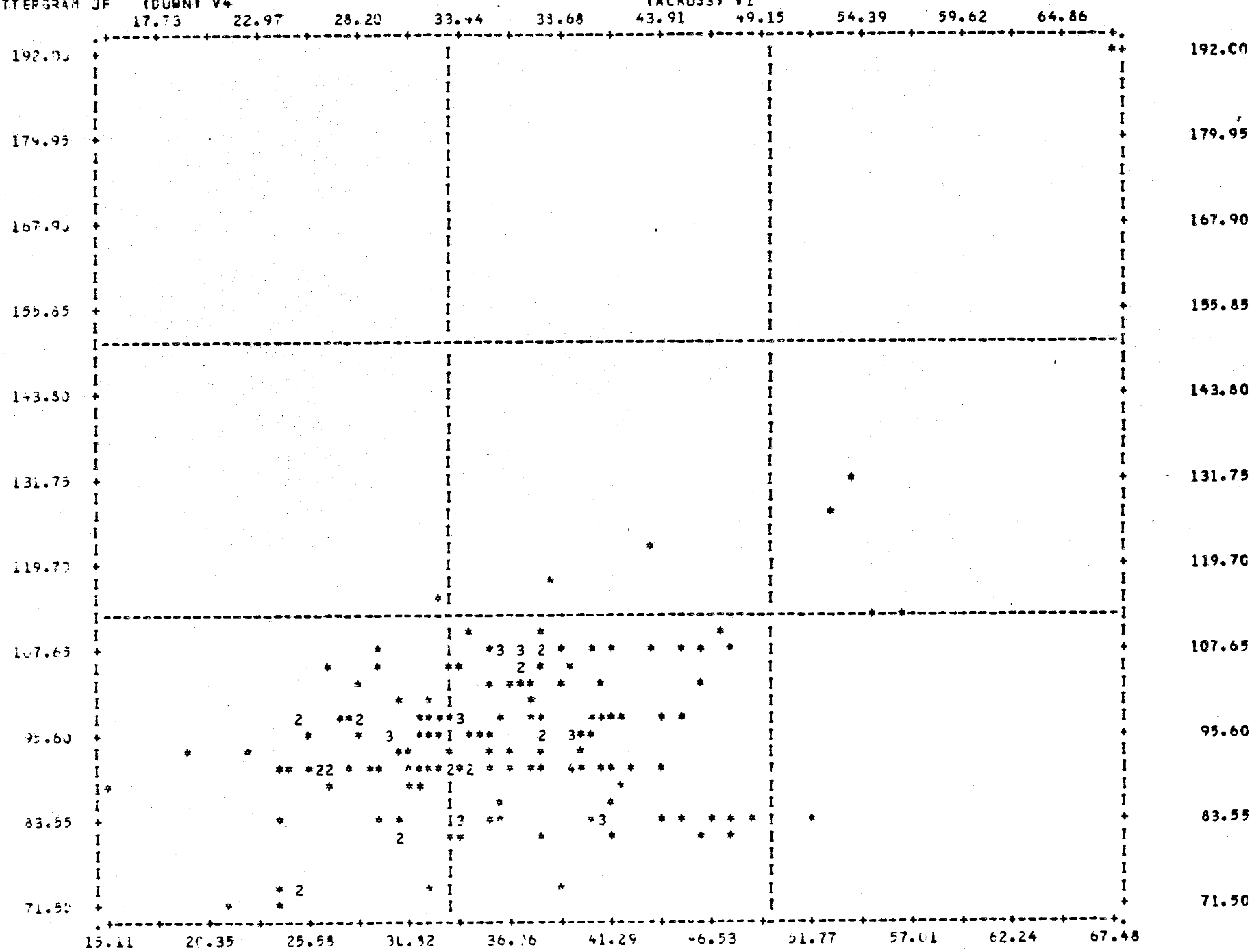
FILE NONAME (CREATION DATE = 07/07/77)
SCATTERGRAM OF (DOWN) V4 (ACROSS) V1

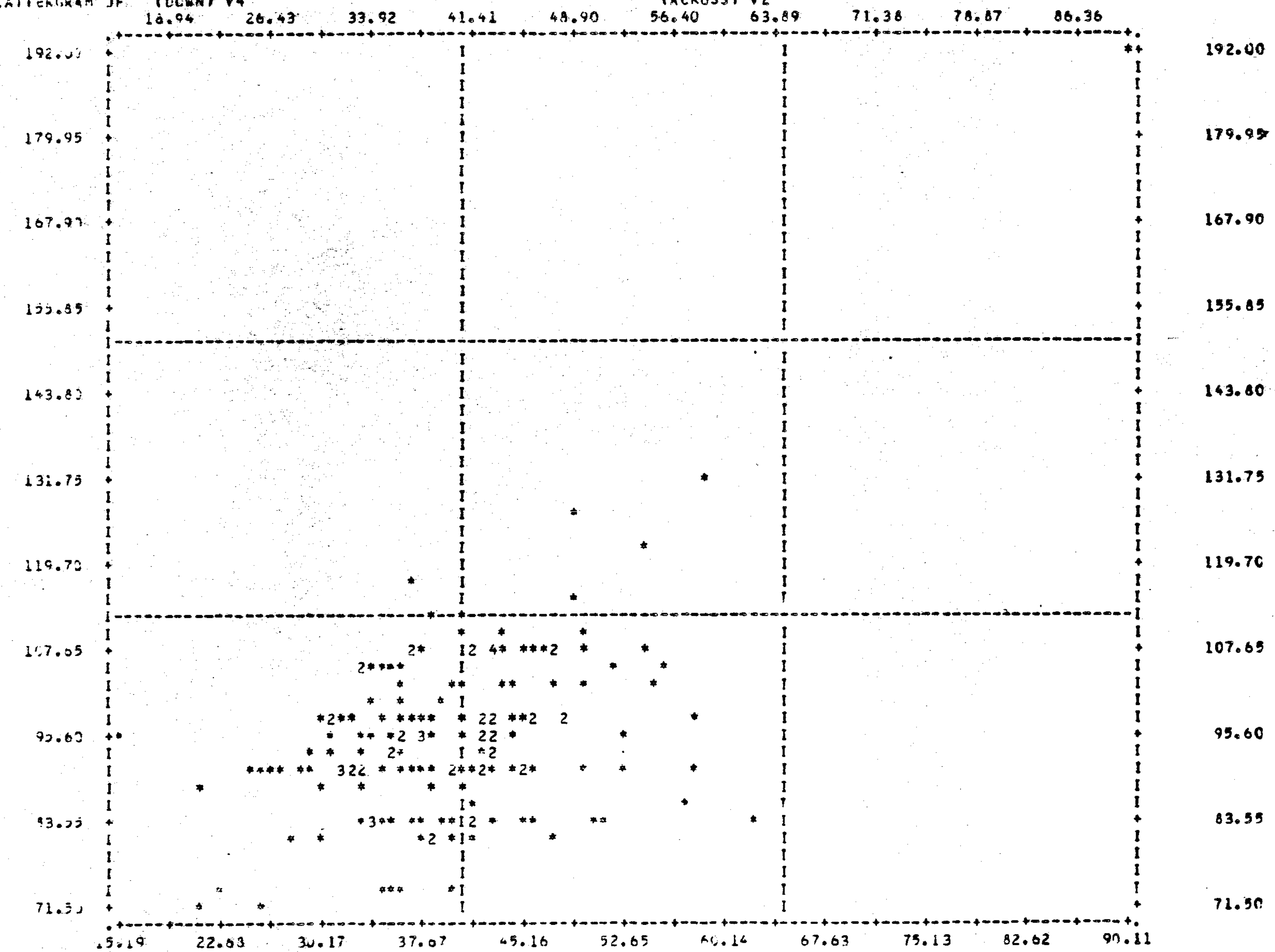


STATISTICS..

CORRELATION (R)-	0.42408	R SQUARED -	0.17985	SIGNIFICANCE -	0.00001
STD ERR OF EST -	11.54275	INTERCEPT (A) -	71.13786	SLOPE (B) -	0.72001
PLOTTED VALUES -	168	EXCLUDED VALUES-	0	MISSING VALUES -	0

'*********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

FILE NONAME (CREATION DATE = 07/07/77)
SCATTERGRAM OF (DOWN) V4 (ACROSS) V2

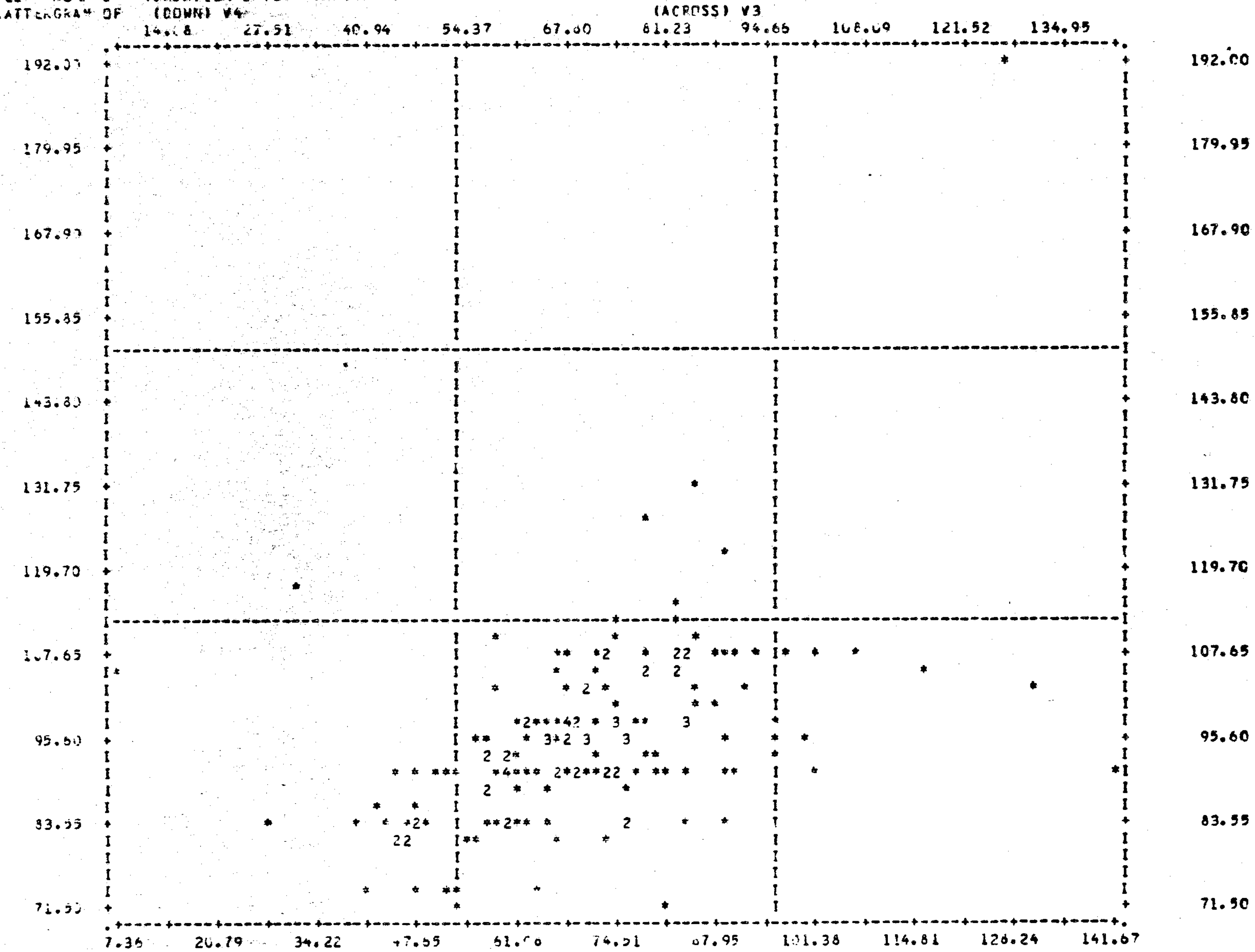


STATISTICS..

CORRELATION (R)-	0.50631	R SQUARED -	0.25635	SIGNIFICANCE -	0.00001
STD ERR OF EST -	1[illegible].99124	INTERCEPT (A) -	67.22659	SLOPE (B) -	0.74134
PLOTTED VALUES -	168	EXCLUDED VALUES-	0	MISSING VALUES -	0

'**********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

FILE NUNAME (CREATION DATE = 07/07/77)
SCATTERGRAM OF (DOWN) V4 (ACROSS) V3



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STATISTICS..

CORRELATION (R)-	0.46825	R SQUARED -	0.21926	SIGNIFICANCE -	0.00001
STD ERR OF EST -	11.262[illegible]	INTERCEPT (A) -	73.30745	SLOPE (B) -	0.33364
PLOTTED VALUES -	168	EXCLUDED VALUES-	0	MISSING VALUES -	0

********* IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.