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Jack Rudolph Walker

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A STUDY OF ELEMENT INDEPENDENCE IN WORK CYCLES

A THESIS

Presented to

the Faculty of the Graduate Division

by

Jack Rudolph Walker

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

June 1959

A STUDY OF ELEMENT INDEPENDENCE IN WORK CYCLES

Approved:

Date Approved by Chairman: June 5, 1959

ACKNOWLEDGEMENTS

The writer would like to express his appreciation to Colonel Frank F. Groseclose and the staff of the School of Industrial Engineering who were very helpful and encouraging in the preparation of this thesis.

Particular thanks are extended to Dr. Harold O. Davidson, Dr. Joseph J. Moder, Jr., Dr. M. Carr Payne, Jr., and Dr. Harold E. Smalley, who served on the Advisory Committee.

A word of appreciation is extended to Dr. Robert N. Lehrer who served on the Advisory Committee in an earlier part of the research for this thesis.

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SUMMARY

This investigation was undertaken to gain further insight into the relationship among the elements of a work cycle, particularly to determine whether or not such elements are statistically independent.

The data were obtained from a micromotion study of two operators, one whose cycle times were statistically stable and one whose cycle times were statistically unstable. These operators performed a short cycle, manual assembly operation in an industrial plant. Work cycles containing major departures from the established work method were eliminated. A twelve element breakdown of the cycle was made for each operator. These data were subjected to Wilks' multivariate test of independence to test the null hypothesis that the elements of the cycle are statistically independent.

The results of the analysis led to an acceptance of this null hypothesis for the statistically stable operator and to a rejection of the null hypothesis for the statistically unstable operator. The only significant correlation found was between the last two elements of the cycle for the statistically unstable operator. From an examination of the films this was believed to be due to the operator's examining the product in order to determine the proper disposition of the completed assembly on those cycles where difficulty was encountered on the next to the last element.

CHAPTER I

INTRODUCTION

There have been few changes in time study practices since its original tenents were developed. The establishment of time study was a part of "Scientific Management" which was later proposed by Taylor as a substitute for the management methods then employed (18).

There have been numerous criticisms of conventional practices in the field of time study. One analysis led Presgrave to conclude in 1945 that time study was in a "most unsatisfactory state," and that methods had been little improved in precision, manner, or uniformity (48).

Various approaches have been suggested by Sylvester (58), Davidson (18), Abruzzi (1), Lehrer (33), Wilkinson (64), Desmond (20), Gomberg (25), and others. Several of these advocate a statistical approach. This move toward a statistical frame of reference was made in an effort to improve the reliability of time study results.

Time study controversy seems to be concerned with two general assumptions: first, that time study elements are statistically independent; and second, that time study men can adequately appraise operator performance using normalizing techniques.

This study is concerned with the assumption that time study elements are statistically independent.

The several conventional standard data systems are founded on the theory that manual activity may be sub-divided into readily identifiable elements of work and that the work content for a given element is the same regardless of where or by whom the element is performed. The theory further holds that the work content of a manual operation is the sum of the times for the individual elements comprising the operation.

An acceptable time study practice is to base work content on normal time, that is, the actual time which has been leveled. Actual time is proportional to normal time if the performance level is constant. Actual time was used in this study on the assumption that operator performance was constant. Hence, results based upon actual time values are presumed to be applicable to work content considerations.

If two different operations, (1) and (2), are divided into their individual elements, 1, 2, . . . , they can be illustrated as follows:

Operation (1) 1 2 "3" 4 5 6

Operation (2) 1 2 3 "4" 5 6 7 8

Suppose element "3" of Operation (1) is the "same," by the definition used in standard data systems, as element "4" of Operation (2). Element 2 of Operation (1) is not the same as element 3 of Operation (2), and element 4 of Operation (1) is not the same as element 5 of Operation (2). The observed time for element "3", on the ith cycle, of Operation (1) could be represented by:

$$y_i = a + bx_{2i} + cx_{4i} + e_i \text{ and}$$
$$E(y_i) = \mu_y = a + b\mu_2 + c\mu_4$$

a, b, and c are constants

x_{2i} = observed time for element 2 on the ith cycle

x_{4i} = observed time for element 4 on the ith cycle

$E(y)$ = the expected value of y

e_i = an error due to both timing and operator activity variation

μ_2 = mean of element 2

μ_4 = mean of element 4

The observed time for element "4" of Operation (2) could be represented in a similar manner as follows:

$$y_i = a' + b'x'_{3i} + c'x'_{5i} + e_i$$
$$E(y_i) = \mu'_y = a' + b'\mu'_3 + c'\mu'_5$$

If we accept the assumption of validity of standard data systems, then $\mu_y = \mu'_y$, and if the elements are independent, i.e., $b = b' = c = c' = 0$, then, this implies that $a = a'$. If, however, the elements are not independent, acceptance of $\mu_y = \mu'_y$ implies that $a + b\mu_2 + c\mu_4 = a' + b'\mu'_3 + c\mu'_5$. Since the latter is not plausible for a large variety of operations, establishing the independence of element times will add support to the use of standard data systems.

This arguement could be extended to cover all of the elements in the work cycle, which is, in fact, what this study tested using Wilks' multivariate test of independence to show that time study elements are statistically independent.

CHAPTER II

REVIEW OF THE LITERATURE

Abruzzi (1) has stated that the assumption of independence is largely unjustified, and that relationships among parts of a motion cycle are partially a function of the operator who is observed. He also suggests that there is a relationship between degree of dependence and the number and size of parts into which the job cycle is analyzed.

Earlier work by Barnes (5) indicated an interaction between element times; that is, if distance was manipulated as a variable, the time required for the transport motions varied as would be expected, but the time required for grasping was also affected. Interaction appeared in both of these studies. This is, however, a dependence among the mean times, not in the element times within the individual cycles.

In a study from the Psychological Laboratories at the University of Wisconsin (55), the components of movement in an assembly type operation were investigated. In this motion pattern the subject was required to grasp a part, move it, position and release it, and finally reach back to the supply of parts. The results indicated that correlations may exist only for certain elements, perhaps between those involving difficult manipulations and between adjacent elements.

Nadler and Denholm (41) Performed an experiment in which subjects had to reach to and manipulate rotary switches. The object of this study was to determine what effect the addition or elimination of an element of work would have on established therblig times within a cycle. Observers found that the original total cycle time and times for adjacent therbligs were significantly affected. The conclusion was that the division of an operation into therbligs for standard data purposes was unwarranted.

Ghiselli and Brown (23) performed a simple key-tapping experiment. They observed that by the elimination of two of the movements the cycle time was not reduced by as much as one would logically expect, thereby indicating interaction between the elements. They concluded that an operator works on an operation as a totality, and that each part of the operation affects all other parts. Buffa (13) in an experiment to gain further insight into the basic additivity of universal standard data elements, seemed to refute the results of the key-tapping experiment of Ghiselli and Brown (23). It should be pointed out, however, that the basis for Ghiselli and Brown's (23) study was element times while the basis for Buffa's (13) study was therblig times.

Barnes and Mundel (6, 7, 8, 9, 10) found, while studying the time required to position pins in bushings with beveled holes, that certain therbligs in the cycles were interrelated; hence, standard times for certain therbligs cannot be given as independent values. Davidson (19) reported on experiments conducted by graduate students, Moffat and McClure. The experimenters used a simple task of the "post and washer" variety in reaching the same conclusions as did Barnes and Mundel.

Gomberg (25) expressed his views on standard data as follows:

> Basically, standard data systems may be divided into two categories: the macroscopic and the microscopic.
>
> The macroscopic school generally formulates its data in terms of sizeable job elements that reappear in many operations. The microscopic school formulates its data in terms of minute muscular reactions, or therbligs.

There are several standard data systems currently in use. They are either the "element" type, the "motion" data type, or a combination of the two. Davidson (18) questioned the accuracy of all standard data systems on the basis that if the values of one system are accurate, then different values from other systems cannot be accurate. His findings do not establish which one of the systems is valid.

Balkcom's (3) study was an evaluation of results attained by three standard data systems. The results:

> offered ample evidence to prove that there is significant difference in the ability of the three standard data systems under consideration to measure the time for a short manual operation. All three of the systems indicated a general lack of agreement between the elements of the synthesized cycle and the elements of the film cycle, as was exemplified by the fact that there was an absolute deviation of 27.86 per cent between the synthesized element times and the film element times.

Green's (28) investigation studied primarily the element-time distributions for an industrial operation; one of the secondary objectives was to investigate element independence. One of the results of this study showed evidence of independency among the elements of the operation. Green pointed out the limitations of his study by noting the small sample used (one operator, one method). He recommended that a rigorous study be made of element independence.

Perkins (47) followed Green's recommendation and proceeded to investigate the relationships among and between elements in the work cycle. The results were as follows:

> It was found that there was evidence of correlation among the time values for the elements of a work cycle for both a five and two element breakdown. In addition, the following conclusions were drawn on the basis of the test results:
>
> 1. There was an indication that the degree of correlation among the elements of a cycle does not remain constant for the same operator during the work shift.
>
> 2. The nature and extent of correlation among the elements of a work cycle from period to period appeared to depend on the operator.
>
> 3. It appeared that in those film sequences where the degree of correlation was found to be the highest, there was a concentration of variables such as fumbles, slight delays in positioning the parts, and dropping extra parts.
>
> 4. There was an indication that the degree of correlation among the elements of the five element breakdown was decreased by combining those elements into a two element breakdown of the operation.
>
> 5. The grouping process did not decrease the degree of correlation among the elements to the same extent for the same operator or data for different shots.

6. The stable and unstable operators exhibited similar characteristics in regard to the degree and extent of correlation among the elements of the cycle.

Perkins recommended that a further analysis be made using a twelve element breakdown, treating them in a similar manner as he did the five and two element breakdown and comparing the results.

The studies cited above have some exploratory value although they cannot be considered conclusive because of certain inherent limitations. Many of the studies were performed under laboratory conditions, using highly motivated test subjects performing simple tasks. The results obtained under these conditions may not be comparable to those found in actual operations. In other studies the basic data were not evaluated statistically and no attempt was made to determine the statistical significance of the results.

The present investigation followed Perkins' (47) recommendation that there be employed the original twelve element breakdown of the industrial operation which he studied for element independency and that the results be statistically evaluated.

CHAPTER III

OBJECTIVES

The reliability of the standard data concept depends largely on the hypothesis of additivity of element times. If the additivity hypothesis can be accepted generally, then considerable research remains to be done in developing a workable standard data system for all classes of motions comprising elements.

The objective of this investigation was to study the relationships among the elements of a work cycle to determine if they were statistically independent. The solution to the problem, therefore, involved accepting or refuting statistically the null hypothesis that the elements of the cycle are statistically independent.

CHAPTER IV

PROCEDURE

The data used in this investigation were available from a research project which began in 1951, under the direction of Dr. Lehrer and Dr. Moder, in the School of Industrial Engineering at the Georgia Institute of Technology. The overall purpose of this project was to contribute a better understanding of the characteristics of a worker's performance on manually controlled, repetitive operations.

These data available from the research project: 1) Were obtained from more than one operator, 2) Represented a sample size large enough to obtain valid statistical results, 3) Represented an operation established for more than three months, 4) Were obtained from experienced operators, 5) Were available on film so that a micromotion study could be made.

Taft (59) utilizing a high-speed camera (2,000 frames per minute), took 15,000 feet of film of nineteen operators at intervals of approximately one hour. He obtained from twelve to fifteen cycles per film sequence.

Taft made micromotion studies of each of the work cycles which were broken down into the following twelve elements:

1.	Get barrel TE, ST, and G	Barrels are in containers directly behind fixture and drive nuts.

2.	Place barrels in fixture TL, P, A, and RL	Barrels are placed in holding fixture, top opening up
3.	Get writing units TE, ST, and G	Writing units are directly to left and right of holding fixture
4.	Place writing units in barrels TL, P, A, and RL	Writing units are placed in barrels, point down
5.	Get drive nut TE, ST, and G	Drive nuts are in container directly behind fixture
6.	Place drive nut on unit TL, P, A, and RL	Drive nuts are placed over top of writing unit
7.	Get ferrule TE, ST, and G	Ferrules are in containers directly in front of fixture
8.	Place ferrule over drive nut TL, P, A, and RL	Ferrules are slipped over drive nuts
9.	Get complete unit TE and G	The complete units are grasped in order to be removed from the fixture
10.	Place complete unit in staking device DA, TL, and P	The complete units are removed from the holding fixture and placed in the staking device

11. Stake ferrule and remove unit from staking device A, H, and DA	The ferrule is staked and the complete unit is removed from the staker
12. Aside assembled unit to container TL and RL	The assembled unit is disposed to container on right of operator

Each element was broken down into therbligs and recorded by frame number. These recordings converted to times in minutes were used as the basic data for this investigation.

Summers (57), using the above data, undertook a study to evaluate the relationship between cycle time stability and the characteristics of the work time distribution. The statistical characteristics for this investigation were the mean time, the total variance, the variance between periods of observations, the skewness, the peakedness, the goodness of fit of the Normal Curve, the Log Normal Curve and the Pearson Type III Curve. The "Variance between Periods" was used as a measure of the level of stability for each operator. The results of these calculations (57), using data from Taft's (59) study, were used in the present investigation in the selection of operators for study, i.e. one whose cycle times were statistically stable and one whose cycle times were statistically unstable.

Two operators were chosen in accordance with the established level of stability criteria (57). The operators were designated by Summers (57) as Q and K. Operator Q represented the statistically stable operator and is hereafter called Operator One. Operator K represented the statistically unstable operator and is hereafter called Operator Two. The following results were obtained by Summers (57) in his analysis of variance:

Operator	Standard Deviation between periods	Standard Deviation within periods
One	$s_m = 5.3$	$s_w = 19.8$
Two	$s_m = 21.1$	$s_w = 25.6$

In the present study an analysis was made of the data from the film analysis sheets for each operator in order to determine the variations in motion times which occurred in each cycle. Some of the cycles contained variables which could not be considered as a normal part of the work cycle. The variables which were selected and eliminated due to assignable causes by Perkins (47) were:

1. Inspection delay - a prolonged visual or physical inspection of an assembled or a subassembly part. The workplace and required motions were methodized to such an extent and the parts were of such a uniform nature that assembly normally proceeded with little if any inspection.

2. Bad part - occurred when an assembly operation could not be accomplished with the part originally selected necessitating the replacement of the part with another. This represented a major departure from the normal work cycle which to some extent could be corrected. Theoretically this could be eliminated by better quality control.

3. Part stuck in staker - an occurrence which was due to the improper functioning of the mechanical staking device. This source of variation was readily apparent and subject to elimination.

4. Distraction - occurred when the operator's attention was purposely and noticeably directed to an object other than the assembly operation, talking to another person and reading while engaged in the assembly operation.

No attempt was made to eliminate the cycles which contained minor departures from the established method such as momentary fumbles, slight delays in positioning parts, and dropping extra parts, since they were considered to be an inherent part of the operation by virtue of their small size.

The element times used in this investigation were obtained by taking readings for the hand which was last to complete the preceding element and subtracting the reading for the hand which was last to complete the element being considered. The element time was taken directly from the film analysis sheets for operators one and two and recorded in thousandths of a minute.

Wilks' multivariate test of independence was used in this investigation to test the data from the film analysis sheets to determine whether variables (element times), in a given set, which are normally distributed, are mutually independent, i.e. the covariances $\sigma_{ij} = 0$ for $i \neq j$ (65, p 242). Defining $\sigma_{ij}^{(o)}$ as follows:

$$\sigma_{ij}^{(o)} = \begin{cases} \sigma_{ij}; & i = j \\ 0; & i \neq j, \end{cases}$$

we can test the mutual independence of the element times using the following null hypothesis:

$$Ho: \sigma_{ij} = \sigma_{ij}^{(o)}$$

The likelihood ratio for testing this hypothesis is:

$$L = \frac{\left| T_1 \right|^{\frac{N}{2}}}{\left| T_2 \right|^{\frac{N}{2}}}$$

where L represents the likelihood ratio and N represents the sample size. $\left| T_1 \right|$ and $\left| T_2 \right|$ represent determinants of the two "Covariance matrices." $\left| T_1 \right|$ refers to the case where the presence of correlation is assumed; this is a symetric matrix. $\left| T_2 \right|$ refers to the case where the absence of correlation is assumed; thus, the elements s_{ij} of $\left| T_2 \right|$ are zero if $i \neq j$ and are the time study element variances if $i = j$.

In the application of Wilks' (65) multivariate test of independence, the ratio is developed from the following matrices:

$$L = \frac{\begin{vmatrix} s_{11} & s_{12} & \cdots & s_{1p} \\ & s_{22} & \cdots & s_{2p} \\ & & \ddots & \vdots \\ & & & s_{pp} \end{vmatrix}^{\frac{N}{2}}}{\begin{vmatrix} s_{11} & & & \\ & s_{22} & 0 & \\ & 0 & s_{33} & \\ & & & \ddots \, s_{pp} \end{vmatrix}^{\frac{N}{2}}}$$

where there are p variables (elements). The s_{ij} terms are computed from

$$s_{ij} = \frac{\sum_{k=1}^{N} (X_{ik} - \bar{X}_i)(X_{jk} - \bar{X}_j)}{N}$$

$$= \frac{\sum_{k=1}^{N} X_{ik}X_{jk}}{N} - \bar{X}_i\bar{X}_j$$

where X_{ik} and X_{jk} refer to the observed times for elements i and j on the kth cycle, respectively. When i = j, the formula reduces to

$$s_{ii} = s_i^2 = \frac{\sum_{k=1}^{N} (X_{ik} - \bar{X}_i)^2}{N}$$

$$s_i^2 = \sum_{k=1}^{N} (X_{ik})^2 - (\bar{X}_i)^2$$

Each of the s_{ij} terms were computed by the IBM 650 Digital Computer located in the Rich Electronic Computer Center of the Georgia Institute of Technology, using Intercorrelation Program (ST - 09). The output card format for this program is:

1. Sums
2. Cross - product sums
3. Means
4. Covariances
5. Sigmas
6. Correlation coefficients
7. N_1 the number of cycles

Output identification number four identified the covariances which were the matrix entries for the likelihood ratio determinant. The L value represents the likelihood that the hypothesis of independence is true as described by Wilks (65). It was, however, convenient to use $L^* = -2 \text{Log}_e L$, since $-2 \text{Log}_e L$ has approximately the same distribution as Chi-square, for large samples (65), with $p(p-1)/2$ degrees of freedom, where p represents the number of elements. In this study, it was considered appropriate to reject the null hypothesis if the value of L* exceeded the 95 per cent point of the Chi-square distribution, i.e., an α risk of five per cent was used.

In order to compute L, the determinants $|T_1|$ and $|T_2|$ were evaluated. This evaluation was made using the IBM 650 and the FOR TRANSIT Program.

The capacity of the IBM 650 Digital Computer, using the FOR TRANSIT Program, was exceeded in the computation of the L value for each operator. The capacity of the computer, in the use of this program, is between the limits of 10^{49} to 10^{-51}. These limits were exceeded because of the extreme range of covariance values obtained. For this reason, the matrix of correlation coefficients was used in place of the covariance-variance matrices. The justification of this transformation is given below

$$\left|s_{ij}\right| = \begin{vmatrix} s_1^2 & s_{12} & \cdots & s_{1N} \\ \vdots & & & \vdots \\ s_{N1} & s_{N2} & \cdots & s_N^2 \end{vmatrix} =$$

$$s_1 \begin{vmatrix} s_1 & \frac{s_{12}}{s_1} & \cdots & \frac{s_{1N}}{s_1} \\ \vdots & & & \vdots \\ s_{N1} & s_{N2} & \cdots & s_N^2 \end{vmatrix} = \cdots =$$

$$\prod_{i=1}^{N} s_i \begin{vmatrix} s_1 & \frac{s_{12}}{s_1} & \cdots & \frac{s_{1N}}{s_1} \\ \vdots & & & \vdots \\ \frac{s_{N1}}{s_N} & \frac{s_{N2}}{s_N} & \cdots & s_N \end{vmatrix} =$$

$$\prod_{i=1}^{N} s_i \prod_{j=1}^{N} s_j \begin{vmatrix} 1 & \frac{s_{12}}{s_1 s_2} & \cdots & \frac{s_{1N}}{s_1 s_N} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \frac{s_{N1}}{s_N s_1} & \frac{s_{N2}}{s_N s_2} & \cdots & 1 \end{vmatrix}$$

$$s_{ij} = \prod_{k=1}^{N} s_k^2 \begin{vmatrix} 1 & r_{12} & \cdots & r_{1N} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ r_{N1} & r_{N2} & \cdots & 1 \end{vmatrix}$$

$$L = \frac{\begin{vmatrix} s_1^2 & s_{12} & \cdots & s_{1N} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ s_{N1} & s_{N2} & \cdots & s_N^2 \end{vmatrix}^{\frac{N}{2}}}{\begin{vmatrix} s_1^2 & & & 0 \\ & s_2^2 & & \\ & & \ddots & \\ 0 & & & s_N^2 \end{vmatrix}^{\frac{N}{2}}}$$

$$L = \left[\prod_{k=1}^{N} s_k^2 \right]^{\frac{N}{2}} \frac{\begin{vmatrix} 1 & r_{12} & \cdots & r_{1N} \\ \vdots & & & \vdots \\ r_{N1} & r_{N2} & \cdots & 1 \end{vmatrix}^{\frac{N}{2}}}{\left[\prod_{k=1}^{N} s_k^2 \right]^{\frac{N}{2}}}$$

$$L = \begin{vmatrix} 1 & r_{12} & \cdots & r_{1N} \\ \vdots & & & \vdots \\ r_{N1} & r_{N2} & \cdots & 1 \end{vmatrix}^{\frac{N}{2}}$$

The values of L were determined by computing the determinant of the matrix of correlation coefficients, again using the FOR TRANSIT Program on the IBM 650 Digital Computer. The sample calculations involved in computing L* are shown in Figures two and three in the Appendix.

CHAPTER V

DISCUSSION OF RESULTS

The calculated L* values which were obtained for operators One and Two were used to test for element independence, at the five per cent significance level. These calculated values are shown in Figures two and three of the Appendix.

An L* value of 78.506 was obtained for Operator One, which corresponds to a significance level of approximately 14 per cent (46). Thus, the elements as originally defined were concluded to be statistically independent. Also noted was the fact that this same conclusion was reached from an inspection of the correlation coefficients which vary in the range expected for the sample sizes involved, under the null hypothesis that ρ, the universe correlation coefficient, is zero.

The L* value of 93.239 was obtained for Operator Two, which corresponds to a significance level of approximately 0.2 per cent (46). Hence, the conclusion was that the elements involved here were correlated. The only significantly large simple correlation coefficient for this operation was 0.52, as shown in Table four of the Appendix, for elements eleven and twelve. The elements involved were

Element Eleven - Stake ferrule and remove assembled unit from staker

Element Twelve - Aside assembled unit to container

These results indicate that correlation may exist only for some elements, perhaps between adjacent elements. These results agree with those of Abruzzi (1), Barnes and Mundel (6, 7, 8, 9), and Smader and Smith (55).

A re-examination of the films and the film analysis sheets for Operator One and Two indicated that many of the work cycles contained minor variations. These variations were due to the operator and were in the form of momentary fumbles, slight delays, and extraneous movements. They were found to occur very frequently and appeared to be a function of the small size of the parts involved in the assembly operation. The work cycles containing these variations were not eliminated since they were considered to be an inherent part of the operation and it was desired to preserve the actual work situation as closely as possible. Operator Two paused momentarily after each faulty staking operation (element eleven), examining her work to determine the proper disposition of the completed assembly (element twelve). This was due to a faulty staking machine and could be eliminated. An elimination of the faulty staking machine would probably eliminate the interdependency found between elements eleven and twelve.

A basic unit of motion always ends when its purpose is accomplished. Throughout the course of the motion, muscular control is directed toward completing the motion as required. No muscular control can be directed toward carrying out the motion that is to follow until the motion in progress is completed. As soon as it is completed, muscular control may be applied immediately to start the next motion. There can be no overlap in the use of muscular control between two successive motions. However, in performing a sequence of motions, the characteristics of a given motion may be influenced, at times, by the adjacent motions. The influence of the associated motions is such that the performance of a motion to carry out a staking or a placement action in one instance may not be delayed through being in the end of a series of motions requiring no visual attention. In another instance the staking motion may be the only one in a series of motions to require close visual attention; and therefore, it will be delayed.

Thus, in those cycles where a faulty staking operation occurred, visual attention was required in order to determine the proper disposition of the completed assembly. These results indicate that correlation may exist only for some elements, perhaps between adjacent elements.

The present study was based on an element breakdown. However, all elements were comparatively short, comprising two, three, or four therbligs; whereas, other investigations cited in this study were based on either longer elements or therbligs.

While the results of this investigation do not reject the hypothesis of statistical independence, neither do they prove that interdependence will not exist under certain circumstances. It could, for example, exist between certain types of elements not represented in the task which was studied in this investigation. It may exist as a function of the way in which some, but not all, operators perform a given task. It may exist as a function of the way in which the task is defined into elements (i.e. the element breakdown). In fact, there is direct evidence for this latter conjecture in the fact that Perkins' (47) investigation on the same data used in this study did indicate the presence of interdependence when the total work cycle was described by means of a two-element, and a five-element breakdown.

The results of the present investigation using a twelve element breakdown are compared with those of Perkins (47) who used a two element breakdown and a five element breakdown. The results shown below indicate an increasing degree of dependence among the elements as their magnitudes are decreased. These results are in agreement with those of Abruzzi (1,p.156).

Number of Elements in the Breakdown	Probability of Obtaining L* Value When the Elements Are Independent	
	Operator One	Operator Two
2	0.48	0.65
5	0.64	0.76
12	0.14	0.002

In addition, the following conclusions were drawn on the basis of the test results and agree with those of Perkins (47, pp. v,vi).

1. The nature and extent of correlation among the

elements of a work cycle from period to period appeared to depend on the operator.

2. It appeared that in those cycles in which the degree of correlation was found to be the highest, there was a concentration of variables.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The objective of this investigation was to gain further insight into the relationship between the elements of a work cycle, particularly to determine if they were statistically independent. The data used was taken from an actual work situation in industry.

The results cannot be considered conclusive, but must be viewed in the light of study limitations. The investigation covered only one assembly operation performed by two operators in one plant.

The null hypothesis of this investigation was that the elements of the cycle are statistically independent. The interpretation of the results indicate that the hypothesis can be accepted for the statistically stable operator and rejected for the statistically unstable operator.

The results of this investigation indicate that independency between elements:

1. May exist only for certain elements
2. Varies with the individual operator

Additional studies should be made of several manual operations in which many operators are employed and in which the sequence of elements of the operations are changed at random. The results of this proposed study should be compared with the findings of this investigation.

A P P E N D I X

ANALYSIS SHEET

FOR

T-600 BALL POINT PEN

Operator	Lillie	Time	3:40 PM Cycle 2 Film No. 26
Analyst	G	Date of Analysis	June 12, 1953
Time Unit	K		

	Frame No.	Subtracted Time		Frame No.	Remarks
	LH	LH	RH	RH	
	482			491	
Get Bbl.-TE,ST, & G	475	05	23	468	
Place Bbl.-TL,P,A, & RL	458	17	31	437	
Get Unit-TE,ST, & G	437	21	31	406	
Place Unit-TL,P,A, & RL	409	28	58	348	
Get Dr. Nut-TE,ST, & G	395	14	16	332	
Place Dr. Nut-TL,P,A, & RL	331	64	28	304	
Get Ferrule-TE,ST, & G	300	31	25	279	
Place Ferrule-TL,P,A, & RL	242	58	27	252	
Get Comp. Unit-TE, & G	239	03	09	243	
Place Comp. Unit-DA,TL & P	222	17	25	218	
Stake-A,H, & DA	117	105	101	117	
Aside-TL, & RL	102	15	12	94	Transferred pens to RH

Figure 1.

Sample Film Analysis Sheet

OPERATOR I

66 df

N = 61

$$L = r^{\frac{N}{2}}$$

$$L = (0.2757)^{\frac{N}{2}}$$

$$Log_{10}\ L = \frac{N}{2}\ Log_{10}\ (0.2757)$$

$$2\ Log_{10} = 61\ Log_{10}\ (0.2757)$$

$$2\ Log_{e}\ L = (61)\ (2.3)\ Log_{10}\ (0.2757)$$

$$L^* = -2\ Log_{e}\ L = -(61)\ (2.3)\ Log_{10}\ (0.2757)$$

$$L^* = -(61)\ (2.3)\ (-1 + .44044)$$

$$L^* = (-140.3)\ (-.55956)$$

$L^* = 78.506$ (Significance level of approximately 14 per cent)

Figure 2.

Sample Calculations Involved in the Computation of the L, and L*, Values for the 12 x 12 Matrix

OPERATOR II

66 df

N = 73

$$L = r^{\frac{N}{2}}$$

$$L = (0.2784)^{\frac{N}{2}}$$

$$\text{Log}_{10}\ L = \frac{N}{2}\ \text{Log}_{10}\ (0.2784)$$

$$2\ \text{Log}_{10}\ L = 73\ \text{Log}_{10}\ (0.2784)$$

$$2\ \text{Log}_e\ L = (73)\ (2.3)\ \text{Log}_{10}\ (0.2784)$$

$$L^* = -2\ \text{Log}_e\ L = -(73)\ (2.3)\ \text{Log}_{10}\ (0.2784)$$

$$L^* = -(73)\ (2.3)\ (-1 + .44467)$$

$$L^* = -(167.9)\ (-.55533)$$

$L^* = 93.239$ (Significance level of approximately 0.2 per cent)

Figure 3.

Sample Calculations Involved in the Computation of the L, and L* Values for the 12 x 12 Matrix

Table 1. Element Times in Decimal Minutes for Operator One

Cycle	Elements 1	2	3	4	5	6	7	8	9	10	11	12
1	014	031	031	058	016	028	025	037	003	021	101	012
2	017	020	020	039	015	034	026	031	005	021	091	024
3	026	036	027	040	061	054	025	048	005	024	025	018
4	020	019	019	058	022	034	026	031	004	017	025	013
5	034	018	029	034	013	045	025	046	003	020	025	017
6	018	020	015	050	017	034	019	030	004	017	024	026
7	048	015	016	050	014	043	022	026	004	019	027	014
8	018	018	031	062	011	067	036	028	003	016	028	011
9	026	018	028	046	016	047	015	025	004	017	026	013
10	018	016	021	063	015	038	043	061	004	027	034	012
11	033	016	015	034	014	060	027	040	018	029	013	016
12	028	018	015	051	011	054	021	029	004	020	019	008
13	018	007	018	055	013	035	016	023	004	017	021	013
14	017	028	015	055	034	012	017	034	003	015	021	014
15	018	016	016	064	013	053	016	023	007	016	021	004
16	019	021	012	056	015	043	022	051	004	015	024	011
17	019	025	012	042	014	025	020	037	011	017	025	011
18	018	015	020	055	016	026	016	024	005	028	006	013
19	018	021	016	054	014	038	019	025	005	030	031	011
20	018.	033	014	056	017	051	024	024	006	029	012	013
21	020	016	015	034	016	040	018	032	003	029	011	011
22	017	024	040	039	015	033	015	029	007	028	014	018
23	011	032	013	034	012	030	018	045	007	027	013	013
24	019	022	030	041	015	035	022	029	007	027	009	015
25	021	021	032	034	013	064	017	015	003	040	009	012
26	027	018	012	045	014	038	033	020	006	027	017	012
27	039	021	015	055	015	031	017	025	006	026	013	012
28	022	019	012	038	015	052	017	028	004	026	018	013
29	023	015	021	066	013	029	021	023	006	038	021	014
30	020	019	025	056	022	057	017	024	005	018	020	014
31	020	018	023	042	016	033	022	028	004	046	010	011
32	019	018	050	042	030	039	020	024	004	039	007	013
33	017	022	012	033	019	059	026	028	007	026	011	014
34	019	044	034	033	018	025	027	035	004	020	034	019
35	019	017	018	039	017	035	038	045	004	014	028	012
36	030	017	022	034	025	040	018	017	008	017	030	012
37	021	020	029	047	016	053	049	047	006	014	027	013
38	016	032	023	043	018	043	019	036	007	029	028	013
39	019	014	032	056	017	056	022	022	007	021	034	019
40	017	017	045	032	026	036	015	036	007	020	029	013
41	020	016	016	034	011	045	019	036	006	015	028	017

Table 1. Element Times in Decimal Minutes for Operator One

(Continued)

Cycle	Elements											
	1	2	3	4	5	6	7	8	9	10	11	12
42	018	022	013	035	010	067	020	024	007	021	021	016
43	019	026	019	042	013	030	022	021	007	023	041	027
44	023	016	018	034	022	026	021	024	007	013	025	006
45	023	013	042	027	016	037	016	022	012	014	031	012
46	016	023	027	034	012	045	018	040	006	016	024	015
47	017	013	018	037	020	028	022	020	007	027	023	011
48	019	017	037	028	012	039	039	025	006	015	024	026
49	013	017	024	041	017	042	021	037	005	018	024	011
50	013	019	016	044	014	057	024	038	004	019	024	016
51	023	019	013	039	012	037	015	040	009	017	026	014
52	024	017	020	035	013	055	017	025	006	017	026	026
53	016	017	014	043	011	031	021	037	009	016	039	010
54	016	022	012	044	024	028	013	030	008	018	058	011
55	017	021	017	043	027	059	030	026	006	020	024	011
56	014	029	012	058	017	057	028	037	008	036	027	020
57	017	024	019	044	021	065	040	022	007	017	047	010
58	014	035	014	057	021	037	035	027	006	021	036	011
59	019	021	017	093	011	070	022	028	007	019	036	012
60	014	037	022	038	019	034	025	024	007	025	029	014
61	024	045	016	041	020	034	014	029	006	037	035	032

Table 2. Element Times in Decimal Minutes for Operator Two

Cycle	Elements 1	2	3	4	5	6	7	8	9	10	11	12
1	021	029	028	045	015	052	018	023	014	021	031	011
2	014	022	027	044	015	069	021	034	007	028	029	010
3	015	022	027	039	024	044	015	031	008	028	031	010
4	014	041	018	038	016	036	016	027	006	022	031	010
5	015	032	020	068	017	043	019	025	008	026	038	010
6	015	023	020	041	018	055	014	023	012	022	030	011
7	033	017	035	029	016	043	016	029	006	023	032	010
8	015	025	025	034	014	037	032	023	008	026	030	010
9	031	025	019	034	039	058	018	023	010	023	030	012
10	026	029	021	041	012	059	013	026	008	024	040	011
11	015	024	014	036	020	057	020	028	007	034	030	013
12	018	031	015	035	012	059	012	023	007	023	033	012
13	016	035	024	072	017	046	013	021	007	023	042	014
14	018	027	027	035	018	039	020	021	006	028	036	018
15	017	025	020	041	023	049	012	023	007	021	037	016
16	014	023	023	061	013	045	020	024	008	002	033	011
17	017	024	020	031	030	036	015	022	009	022	042	015
18	017	029	025	039	015	050	017	028	008	022	039	014
19	017	031	028	032	022	041	020	021	010	021	030	013
20	020	036	027	036	012	038	016	025	008	025	029	011
21	017	037	013	035	021	039	018	022	011	022	032	013
22	023	030	026	032	016	070	018	023	008	022	029	011
23	015	026	014	037	013	039	016	019	010	033	030	009
24	018	027	016	036	016	044	018	024	007	022	028	010
25	015	023	016	032	020	045	014	020	008	038	039	017
26	015	023	033	055	014	075	013	039	010	021	028	010
27	019	023	016	047	015	057	015	021	007	021	028	012
28	014	024	016	039	012	038	014	024	008	021	033	010
29	016	035	020	031	013	040	019	031	008	026	035	011
30	011	028	027	031	015	063	012	021	009	024	027	011
31	016	023	020	036	018	041	025	022	011	022	029	010
32	014	025	020	037	021	048	020	031	013	020	030	011
33	013	020	018	060	021	075	020	021	008	024	027	011
34	013	029	027	031	015	042	016	026	004	020	030	009
35	014	022	027	039	023	041	014	031	008	026	022	010
36	014	025	016	040	019	046	025	017	010	024	027	010
37	013	029	017	044	014	042	015	040	008	023	027	010
38	013	029	021	036	012	054	022	029	010	022	040	010
39	014	021	038	063	014	053	024	024	008	023	040	009
40	013	022	027	036	011	049	016	021	009	024	027	010
41	014	025	016	037	015	054	019	024	010	021	028	008

Table 2. Element Times in Decimal Minutes for Operator Two

(Continued)

Cycle	Elements											
	1	2	3	4	5	6	7	8	9	10	11	12
42	013	027	015	040	022	051	017	022	008	018	035	012
43	017	036	015	042	019	039	027	026	007	032	029	010
44	012	024	017	063	023	040	014	027	008	022	031	012
45	012	029	015	031	017	077	018	026	010	022	032	011
46	011	030	019	038	013	037	017	024	007	023	028	012
47	012	025	015	037	018	064	014	031	006	020	031	012
48	013	023	021	040	012	051	017	022	010	021	030	012
49	014	027	018	040	015	043	017	027	007	024	040	015
50	011	031	015	036	015	042	016	021	008	021	030	013
51	013	023	019	038	016	042	020	023	008	041	037	013
52	020	039	020	040	020	085	020	021	007	021	053	018
53	015	027	014	033	012	042	013	025	008	025	047	015
54	020	028	013	045	019	044	016	027	005	022	027	012
55	011	022	025	030	013	040	028	028	008	024	040	009
56	013	028	021	038	013	057	022	023	008	022	026	010
57	014	021	016	032	011	043	015	025	009	022	042	011
58	011	028	020	039	015	051	017	021	009	022	027	010
59	012	023	015	042	013	042	014	024	007	022	032	010
60	015	020	015	048	010	063	024	018	009	021	029	012
61	013	023	017	033	011	055	015	024	009	020	026	011
62	011	035	022	037	010	049	027	023	006	020	029	009
63	012	027	014	039	018	060	017	022	008	026	030	010
64	012	020	014	048	014	038	018	026	014	034	029	009
65	013	025	015	034	017	050	016	024	008	024	027	011
66	022	025	017	034	014	033	033	017	009	024	034	010
67	015	023	013	042	011	049	013	025	007	020	031	010
68	014	024	015	031	014	046	021	024	007	023	034	013
69	015	036	015	038	013	050	014	026	006	023	028	009
70	013	025	015	034	012	057	013	022	010	023	030	018
71	015	029	020	037	014	040	014	025	008	023	030	010
72	013	023	018	033	012	063	016	029	010	022	029	010
73	017	034	030	040	026	066	017	023	005	025	030	009

Table 3. Correlation Coefficient - 12 x 12 Symmetrical Matrix for Operator One

1.0000	-.2320	-.0042	-.0571	.0017	.0720	-.0832	-.1106	.0748	-.0013	-.1905	.0325
	1.0000	-.0551	-.0347	.3103	.1250	.0508	.1616	-.0386	.2166	.1948	.3072
		1.0000	-.2302	.1807	-.0231	.0343	-.7330	-.1059	.0636	.0184	.1112
			1.0000	-.0838	.1453	.1111	-.0053	-.2288	.0195	.1218	-.2270
				1.0000	-.0871	.0003	.1013	-.0898	.0342	.0025	.0024
					1.0000	.2316	-.0751	.0597	-.0168	-.1479	-.0432
						1.0000	.3113	-.0757	-.1354	.1610	-.0257
							1.0000	-.0333	-.1693	.1171	.0059
								1.0000	-.0418	-.0409	.0009
									1.0000	-.2929	.1088
										1.0000	.1644
											1.0000

Table 4. Correlation Coefficient - 12 x 12 Symmetrical Matrix for Operator Two

1.0000	.0538	.2481	-.1135	.3295	.0440	0.0000	-.0602	-.0547	-.0418	.1499	.1240
	1.0000	-.0693	-.0403	.0191	-.0305	-.0087	-.0490	-.2496	-.1774	.1512	.0962
		1.0000	.1288	.0507	.0971	.1055	.2139	-.0611	-.0440	.0318	-.1521
			1.0000	.0199	.1053	-.0404	.0571	-.0037	-.0387	.0663	-.0810
				1.0000	.0519	-.0556	-.0428	.0265	.0660	.0243	.2356
					1.0000	-.1295	.0721	.0266	-.1783	-.0148	.0680
						1.0000	-.2055	.0852	.0585	.0035	-.2335
							1.0000	-.0832	-.0310	-.0919	-.2397
								1.0000	.0328	-.1068	-.0845
									1.0000	.0893	.1234
										1.0000	.5164
											1.0000

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