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EFFECTS OF LEARNING ON SHORT-CYCLE OPERATIONS

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I. INTRODUCTION

The problem of predicting the rate at which an employee will learn an industrial operation so that he can perform it at the average pace has not been solved. Our lack of detailed knowledge about learning has made it difficult to readily establish production standards for small runs. Generally, the operator will perform the first cycle in a greater time than what is considered average, and each successive cycle will show some time improvement. However, the rate of improvement will vary depending upon the operator's previous experience, his motivation, the type and complexity of his work, and numerous other factors. The purpose of this paper is to review the work that has been done pertaining to the effects of learning on short-cycle operations and then to present an experimental program that the MTM Association is undertaking to enable them to predict the effects of learning on the establishment of production standards through the use of MTM. The attached Appendix is a bibliography with appropriate discussion of the most relevant work to date on learning curves as applied to production standards.

II. BACKGROUND

Two different approaches have been taken to the study of learning. The most widely used approach will be called the Composite Curve method, and the other approach, which has had little applied use but which as great potential, will be called the Elemental Motion method.

The Composite Curve method. This was first used in the aircraft industry during World War II. The number of labor hours necessary to produce an airplane was plotted against the number of aircraft produced.

This is called the Composite Curve method because the reduction in total time that occurred with every plane was due to a number of different factors. The increased experience of the people in terms of the manual operations, the improved methods that were introduced, and the changes in organization all contributed to this reduction in time.

The aircraft industry kept records of the number of labor hours used in producing each aircraft, and they have been able to draw general conclusions concerning the particular shape and use of learning curves within their industry. The learning curves have been developed well enough to enable these firms to use the curves as a basis for estimating (for bidding and production purposes) the number of hours necessary to produce an aircraft or component. The curves themselves, once they are adopted, probably serve as a motivating function which tends to improve their reproducibility. In other words, these curves are looked upon as goals which everyone tries to attain. This in many cases motivates the people positively if they are not attaining the goal and negatively if they are exceeding it.

When we consider the problem of taking the information that has been obtained in the development of the Composite Curves and using it for other types of operations and industries, we find that there is no real basic quantitative understanding of the factors that have gone into the establishment of the curves. The curves are the result of an averaging-out process between such factors as methods changes, improved skills of the people, organizational changes, and varying motivation. This makes a transfer of the learning information from one industry or operation to another extremely difficult if not impossible. If we continue to use the Composite method, we will have to collect similar information concerning each and every industrial operation in which we are interested in the same manner as the aircraft industry. It is the authors' opinion that, even if this information was collected, no real understanding of what actually goes on in the learning process could be obtained. The basis for this opinion is the great difficulty in obtaining factual information concerning the components that affect the learning curve. Also, the curves would not show the maximum rate at which people are capable of learning -- even average people -- but would have contained in them all the mistakes of organization, poor methods, and improper training.

The Elemental Motion Approach. In recent years a certain amount of work has been done on the study of the methods by which individuals learn basic elemental motions through repeated performance. Much of the work has been centered around the degree of learning with repeated cycles of such hand motions as move and reach and certain manipulative movements. Most of the work has been done by people in the field of applied psychology, and very little has found its way into text books on work measurements.

The general approach to the study of basic elemental learning times has been to select an operation and to run a series of experiments. High speed electronic equipment has been used to record the relatively small time values of each of the elements. The rate at which the time values decrease with repeated cycles is determined. Learning curves are then developed for the various individual elements for the subjects tested. The experiments have been performed in controlled situations where the backgrounds of the operators as well as the degree of motivation have been controlled. This approach provides, in the authors' opinion, a much more basic understanding of what actually happens when an operator starts a new job and what actually happens when he performs repeated cycles of the same operation. This method enables one to focus on the problems that are encountered in the establishment of production standards and directly relates to the actions of the operator in reducing the amount of time it takes to perform a cycle. This method does not have the complicating factors such as methods changes except as the operator changes the basic elemental motions as he repeats the operation. Nor are organizational changes involved.

The elemental approach, therefore, provides an understanding of many aspects which are quite fundamental in predicting how fast an operator can learn a new operation. Questions, such as the following, can be explored by this method:

1. What is the relative learning rate of each element?
2. What is the state of learning at the beginning of each element?
3. Does the learning of one element affect the learning of another?
4. How do the various elements and their resultant learning combine to give the overall average cycle time?
5. Is there a transfer of skills between similar but not identical operations?

The research and experiments that have been performed to date on the Elemental Method have indicated that people have the following general characteristics:

1. Unloaded travel time does not improve much during the repeated performance of a cycle. The literature (Appendix) indicates that approximately 15% improvement can be expected. There are exceptions to this which indicate that where the travel movement has a pre-position or rotation of the hand connection with it, the amount of learning can go up as high as 50 to 60%.

2. Elements involving skill such as positioning, grasping, and assembly exhibit much higher orders of learning than travel elements. Reductions in time of as high as 53% have been experienced on the skill elements.

3. An operator is more skilled in performing some elements than others. Actually, his training in motor skills starts on the first

day he is born. His training is much higher in those areas of travel and reaching than it is in performing certain skilled tasks. For example, his degree of learning in reaching for an object is much higher than that of putting a nut on a bolt.

4. In certain cases the learning of one element affects the learning of another. In statistical terms, this is called interaction, and it occurs primarily in those elements preceding the more skilled operations.

5. The rate of learning of an element usually changes as the number of cycles increase. For example, the initial rate of learning on an operation is very rapid but levels off over a period of time.

6. There is no indication that the rate of learning ever decreases to zero. Learning continues through many thousands and perhaps millions of operations. However, most of the learning is accomplished in the first few thousand cycles.

7. Motivation plays a very important part in a person's ability to learn. Much of the work to date has been done in a laboratory where the motivation can be controlled and kept at a very high level.

8. There are many types of operations where the transfer of skills from one operation to another is definitely accomplished. In other words, in certain types of skilled operations, performance in one type of operation will help and enable the operator to start out at an advanced stage on the learning curve for the next operation.

9. The eyes play a very important role in the development of motor skills. Studies between people who have been artifically blinded and people with sight indicate that both groups learn at somewhat the same rate; however, the people with eyesight tend to be superior regardless of the number of cycles performed.

III. EXPERIMENTAL PROGRAM

The previous paragraphs have attempted to describe the two main approaches to the learning of motor skills. Various aspects of each of the methods have been pointed out and discussed. Since the main objective of our experimental program is to determine how long an operation should be performed before the MTM Standard is obtained, we feel that the second, or Elemental Motion approach, is superior. Our approach will be to perform a series of experiments in which we will record by means of our Electronic Data Collector the basic elemental motion times. As a cycle is repeated, the basic motion times will tend to decrease at a given rate. We can then determine how many cycles it will take before the average time to perform the element equals the MTM elemental time.

The work that has been done to date provides a good background for these types of experiments. The fact that people improve on different elements at different rates, that there may be an interaction between some of the elements, and that learning goes on for long periods of time are important pieces of information to have before starting these experiments.

The work to date (by other people) has been restricted to a very short number of cycles. Most of the work with the exception of Barnes* and Barnes and Amrine** has been limited to as few as 50 cycles or less. The experiments that have been performed have not

* Article No. 11 in Appendix.
**Article No. 1 in Appendix.

been concerned with the attainment of a given standard but with the acquisition of a basic knowledge as to how people learn. The literature does not contain the basic elemental motions that the subjects performed. We, of course, would have to have this information in order to relate what has been done to the attainment of an MTM Standard. For example, we know that the travel movements in certain cases show a reduction of approximately 15% over relatively few cycles, but we do not know the specific travel motions that were performed.

In order to determine how long it takes an average operator to attain the MTM elements, we have set up a number of experiments in the laboratory which simulate an industrial operation and have contained in them most of the MTM elements found in industrial situations. The elements of reach, move, grasp, and travel are the most important and should be studied first. Initially we will use students at The University of Michigan to run through these experiments and to study the characteristics of each of the elements. It will then be necessary to get industrial operators from various plants to come in and re-run the experiments. By this means we can get some idea of the initial experience of industrial operators and also compare industrial operators against students. The purpose in using students, of course, is to enable us to perform the experiments as conveniently as possible. It is going to be rather difficult to get large numbers of industrial operators to sit down and run through these experiments, especially since we will have to run over a large number of cycles; perhaps three to four thousand for each operator. If we find that there is a good relationship between the performance of the operators and students, then we can use students for most of our experiments and still have a good assurance that our curves will be representative of industrial situations.

After we finish this work it will then be desirable to take the Electronic Data Collector to a number of industrial situations where new operators are being introduced to jobs. We will instrument the operations, predict how fast the operator should learn, and then record how fast he actually does learn comparing the differences to see if we have a good prediction technique. As previously discussed, we can expect one difficulty in doing these types of learning experiments in an industrial situation -- in the factory we cannot control the degree of motivation of the operator as well as we can in the laboratory. This will make prediction more difficult, but may also provide insight into just how well industrial operators are motivated.

After we have obtained the time it takes an average operator to attain the basic MTM elements, we will have to develop a method of combining the different rates of learning for each of the elements to obtain a learning curve for the overall cycle. We feel that the curve for the cycle will have to reflect the relative number of the more numerous MTM elements, such as the travels, grasps and moves, in order to reflect the different amount and rate of learning of each of these elements.

APPENDIX

BIBLIOGRAPHY OF LEARNING WITH REGARD TO REPETITIVE OPERATIONS

1. Barnes, Ralph M. and Harold C. Amrine, "The Effect of Practice on Various Elements Used in Screw Driver Work," Journal of Applied Psychology, Vol. 26, No. 2, 1942.

Five operators performed 3400 cycles consisting of the use of a screw driver in turning down a screw. The time for various therbligs was picked up and recorded by means of electronic circuits and a Kymograph. The results of this study are as follows:

a. The total cycle time for 3400 cycles decreased 43%.

b. Transport loaded Therbligs decreased approximately 15% over the total run.

c. The Use Therbligs consisting of the turning down of the screw were divided into two sections. "Use 1" which was the turning of the screw to within an eighth of an inch of being flush with the surface, and "Use 2" being the turning of the final eighth of an inch. A 40% reduction in "Use 1" and a 66% reduction in "Use 2" occurred. The conclusion made was that the greater skill required in "Use 2" brought about the best opportunity for reduction in time.

d. The learning curves for the total cycle time as well as for the various elements within the total cycle did not exhibit the conventional learning plateaus except for very short periods. The plateaus that did exist occurred at different times for different elements. For most of the elements the rate of learning was the highest for approximately the first 900 cycles. The rate of learning then continued to improve but at a somewhat decreasing rate.

e. There was no indication that the learning of this particular operation was complete at 3400 cycles. In fact, there is evidence that, if the experiment were continued, additional learning would have occurred.

2. "A Theory of the Acquisition of Speed-Skill" by E. R. F. W. Crossman. Ergonomics, Vol. 2, No. 2, Februrary 1959, pp. 153-166.

This is a theoretical paper on how people develop speed skills. Speed skills can be thought of as how people learn to perform a repetitive operation efficiently. Crossman's hypothesis is that people learn by selecting the proper method on an elemental basis for a number of methods and that the probability distribution of selection of the correct method improves with repetitive cycles. He gives examples of elements that start off with symmetrically-shaped times and ends up with highly skewed times toward the lower values. He then goes on to develop a theoretical mathematical model which states that the probability of the time it takes to perform a given element will improve over time because of the shift of the distribution. Crossman does not have enough experimental data in his paper to show whether his ideas are correct or not. His hypothesis, that people have available on the elemental basis a number of different methods of doing the same operation, leads to a certain amount of vagueness as to what is considered an elemental function of the operation.

3. "Effects of Sustained Performance on Human Motion." Smith, Patricia Ann and Karl U. Smith, Perceptual and Motor Skills, 1955, Vol. 5, pp. 23-29.

Twenty-three right-handed college females were used for the experiments. An instrument known as the "Universal Motion Analyzer" was used. The subjects turned knobs in a certain sequence on the Analyzer panel. A six-day preparatory training consisting of ten trials per day was given each subject. Then, a sustained practice period consisting of eight weeks with four trials per week was performed. The Analyzer recorded the manipulation time and the travel time for each subject. The conclusions were as follows:

a. The manipulative movement during the six days of initial practice dropped from 11.68 seconds to 7.94 seconds, whereas, during the same period the time for travel movements changed relatively little. The average duration of travel movement in the first practice period was 6.82 seconds. After 60 cycles the travel time was at 6.15 seconds. In addition the standard deviation of the manipulative movement decreased from 2.92 seconds on the first day to 1.34 seconds on the sixth day, indicating that the variance of the manipulative cycle was considerably reduced. The standard deviation for the travel decreased only .02 seconds during the same interval, indicating a very high stability in the variance of this movement.

b. During the sustained period of eight weeks, the score levels for both manipulation and travel were fairly uniform. For example, the manipulation time for the first week was 7.70 seconds and for the ending week was 6.79 seconds with a standard deviation of 1.28 seconds for the first week and 1.38 seconds for the eighth week. This represented a significant difference in the means but not at the rate of the first day of initial practice. The travel time went from 6.35 seconds at the first week to 6.2 seconds at the eighth week, which is significant at the 5% level. The standard deviation for travel dropped sharply from 3.02 seconds the first week to 1.97 seconds the eighth week.

4. "Dimensional Analysis of Motion: IX. Comparison of Visual and Non-Visual Control of Component Movements," Huiskamp, Janet, Robert C. Smader, and K. U. Smith, The Journal of Applied Psychology, Vol. 40, No. 3, 1956.

This paper is concerned with the comparison of subjects that are performing the same motor operation but in which one set of subjects is blindfolded and the others are not. The experiments were run on the University of Wisconsin's "Universal Motion Analyzer." In addition to the rate and degree of learning of blind and non-blind students, the transfer of skills from blind operation to non-blind operation was also examined. An experimental design was used for the test with an analysis of variance performed on the data. The experiments consisted of the turning of knobs in different sequences by 24 university students. The conclusions were as follows:

a. The presence of one's eyesight dominates one's performance. The blind people could not compensate for their loss of vision even with extended practice. Their eyesight tended to dominate their manipulations as well as their travel movements. The blind people were restricted in fine and gross travel movements.

b. Both the blind and non-blind groups tended to show very significant improvements in performance of the manipulative components as practice continued. A significant improvement in the travel movement occurred only with the blind group.

c. In the case of manipulation the rate of learning was about the same for the blind person as the non-blind person except that the blind person took a much higher initial time.

d. The transfer of skills from the blind people to the non-blind people showed that it really didn't matter whether one was trained in the blind group or the non-blind group, because the amount of skill obtained through the repeated practice was easily transferred with little loss.

e. The authors discussed the role of perception in their experiments. They contended that the perceptual loading of the blind group accounted for the significant improvement in the travel time in this group whereas the lack of this perceptual loading in the non-blind group resulted in only a small improvement in travel time during the experiment.

The hypothesis they presented is that the perceptual aspects are not confined to just the search and select Therbligs, but are an important part of all of the basic elemental emotions and that it is somewhat superficial to consider that these Therbligs are not part of the other elements and do not affect their cycle times.

5. "Principals of Design of the Sequential Interval Recorder" by Smith, Karl Hugh and Gerald Rubin, Perceptual and Motor Skills Research Exchange, Vol. 4, No. 1, March, 1952, pp. 1-6.

This is a paper which gives the detailed construction of an interval time recorder which was designed to record small elemental time values. It consists of four decades which are wired with forty recording pens, in such a way that upon a signal the particular reading of each of the decades is recorded by an impulse to a stylus. The pens rest on paper which is driven at a fixed speed. The impulse coming from the decades activates the proper stylus which in turn marks the paper for every element. The paper is then read by means of a decoder chart for the particular locations of the beginning and end points of the elements.

According to the paper, several of these instruments have been produced, but we have found no published papers that have utilized the recorder.

6. "Dimensional Analysis of Motion: No. VII. Extent and Direction of Manipulated Movements as Factors in Defining Motions" by Harris, Schelby J. and Karl U. Smith, The Journal of Applied Psychology, Vo. 38, No. 2, 1954, pp. 126-130.

These experiments were performed on the University of Wisconsin's Electronic Motion Analyzer. Forty-two right-handed men and women from an elementary class in psychology performed the experiments. The experiments consisted of moving knobs through 40, 80 and 120 degrees in both the clockwise and counter-clockwise direction with intervening travel between the knobs. The purpose of the experiments was to determine; if the amount of knob rotation affected the travel time significantly, and if the rate of learning was independent of the amount of knob rotation. The conclusions were as follows:

a. Due to practice, the manipulative movements, which consisted of the turning of the knobs, showed a greater improvement than travel movements. The rate of learning was much faster during the first three days which consisted of 21 total cycles than for the last four days which consisted of 28 additional cycles. The learning rate was much higher for the 120 degree turn than for the 80 degree and likewise for the 80 degree than for the 40 degree turn.

b. The duration of both the manipulative and travel time was significantly increased with the greater movement. In other words, it took longer for the travel time between knobs if the hand moved a knob 120 degrees than if the hand moved the knob 40 degrees. In addition, the relationship between the time to move a knob 40, 80, and 120 degrees remained linear on the first and last days even though the slope of the lines changed. The line slope for the first day was much greater than for the last day.

c. Clockwise rotation of the knobs produced significantly better results than counter clockwise rotations.