"In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institution shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

[illegible signature]"

AN INVESTIGATION OF THE PATTERN OF VARIATION OF CYCLE PERFORMANCE TIMES FOR A REPETITIVE MANUAL OPERATION

A THESIS

Presented to

the Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Martin Hayes Kennedy

June 1957

AN INVESTIGATION OF THE

PATTERN OF VARIATION OF CYCLE

PERFORMANCE TIMES FOR A

REPETITIVE MANUAL OPERATION

Approved:

Date Approved by Chairman: 27 MAY 1957

ACKNOWLEDGMENTS

The author would like to express his thanks and appreciation to the members of his thesis reading committee, Drs. J. J. Moder and J. H. Wahab. A special debt of gratitude is due Dr. R. N. Lehrer, the author's thesis advisor, for his constant wise counsel, constructive criticism, and friendly encouragement.

Thanks are also due to Dr. K. M. Murphy, Mrs. Martha McCalla, and Mr. J. E. Garrett for their real help in editing, typing, and printing the manuscript. Special acknowledgment is given to Dr. B. M. Drucker for his aid in the program design and with the operation of the I.B.M. 650 Data Processing Machine.

The author also wishes to thank the management of Snow's Laundry and Dry Cleaning establishment in East Point, Georgia for the use of their facilities to gather data.

Particular thanks are due the author's parents, whose assistance and confidence made this work possible. And, like most authors, I owe most to my wife for her patience and encouragement throughout this undertaking.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

SUMMARY

The purpose of this investigation was to study a worker's cycle performance times over a period of several days to determine if the cycle times of the worker exhibited any statistically predictable pattern. This presentation also expanded certain portions of the previous research at the Georgia Institute of Technology to the extent that a long cycle, manual, worker-controlled, repetitive, non-assembly type operation was observed for an entire week for each of two operators. This was done to compare the findings of this study with the results of the previous work which investigated the characteristics of a short cycle, manual, worker-controlled, repetitive, assembly type operation.

The work studied in this research was a shirt pressing operation in a laundry in the Atlanta, Georgia area.

Total and modified work-time frequency distributions, the estimates of the first four moments, and the coefficients of variation of each distribution were derived for each half-day, daily, and weekly periods for each operator studied. The total cycle time distributions utilized the raw cycle times whereas the modified cycle distributions were constructed of the raw cycle times with the time consumed by various assignable causes of variation removed.

Linear trend lines, control charts, and various significance tests and comparisons were used to analyze the data. The analysis procedure involved evaluating for the presence of trend, random variation, and a

state of statistical control of the various distributions. Also, the differences between means and standard deviations were tested and compared and the distributions were tested for normality.

The results showed that there was generally no pattern of variation of an operator's cycle times with or without the time consumed by various assignable causes of variation intact. However, the modified cycle time distributions were predominantly in a state of statistical control.

The results of the previous research at the Georgia Institute of Technology were only partially substantiated. The results of this and the previous work agree in that a direct relationship between the mean and the standard deviation of a work-time distribution is indicated. However, the findings of this work pertaining to normality of the distributions differ from the previous studies. The statistics for the modified cycle time distributions in this study were not significantly different from normal in most cases while all of the total cycle time distributions were significantly different from normal. This infers that a long cycle operation may actually have a theoretical normal distribution whereas the theoretical distribution for a short cycle operation is known to be positively skewed.

This study has shown that the concept of normality as applied to theoretical work-time frequency distributions may have some validity. Further basic and applied research into this and other phases of work measurement will result in better techniques and valid concepts to help solve our practical problems.

CHAPTER I

INTRODUCTION

Origin of time study.—During the 1880's and 1890's, Frederick W. Taylor evolved a theory of management, termed "scientific management" by him, which proposed that engineers, by objective analysis, could determine the reasonable capacities of men and machines. His theories were formulated to combat "soldiering" and to replace the haphazard rule of thumb measures then used to determine a "fair day's work". The primary tool in "scientific management" developed and used by Taylor and his associates was called "time study," and except for minor changes in methods and procedures, the practice of time study in much of industry today is basically the same as in Taylor's time.

Current criticism of methodology.—The scientific validity of time study has been questioned time and time again since its inception, despite its widespread acceptance as a scientific tool by industry. As Barbash says,

> The objects of union questioning in time study are . . . such aspects as fatigue allowances, the representative character of the "average" worker whose operations are being timed, and the value judgements involved in setting the standard time an operation requires (1).

The most stimulating critical evaluation to date, emphasizing time study's failure to withstand tests for scientific validity, has been offered by William A. Gomberg, foremost labor spokesman on time study and himself an industrial engineer. He argues

> When you examine the validity of existing industrial time study practice you soon find that you are in a field filled with conflicting methods of observation, conflicting methods of collecting data, conflicting methods of analyzing and interpreting data and, finally, conflicting results. The results are generally accompanied by an insistence that these are scientific results in accordance with the facts (2).

Gomberg believes that the consideration given psychological, physiological, and sociological factors causing variation in the quality of performance and production rate of workers is purely subjective, if they are considered at all, when computing standards (3).

Presgrave, on the other hand, sees the principal worker objections to time study in the air of mystery created by it and in the manner in which it has been misapplied (4). His objections imply but do not state a challenge of the validity of time study practices, although they illustrate that the scientific validity of time study is not the only objection that workers have to it.

Contained in Gomberg's thought-provoking criticism was the suggestion that a statistical approach in viewing the underlying structure of time study be used. He indicated,

> If a time study is to rest on sound logical foundations as a means of predicting future performance from sample studies, then the individual man-machine system for which prediction is being made must be in a state of statistical control (5).

This state of statistical control is defined in terms of a physical constant chance cause system. Taking Shewhart's theories and illustrations as he applied them to quality control (6), and applying them to time study, we find that for a constant chance cause system to exist, performance times, when tabulated in the form of a frequency distribution, must be such that the differences between samples are predictable by probability mathematics. R. N. Lehrer, in applying the chance cause system concepts to the analysis of the rates of production of workers, says,

> Measured quantity of production is always subject to a certain amount of variation as a result of chance. Some stable "system of chance causes" is inherent in any particular scheme of production and evaluation. Variation within this pattern is inevitable. The reason for variation outside this stable pattern may be discovered and corrected (7).

The use of control charts and statistical techniques for evaluation has not only theoretical but also has practical implications because detection and identification of the causes of variation allow themselves to be corrected. Lehrer emphasizes this in asserting,

> Progressive elimination of assignable causes will allow better utilization of industrial facilities and eventually a stable pattern of variation indicative of the presence of a true "system of chance causes" will become evident (8).

With the discarding of assignable causes of variation and the possible emergence of a stable system of chance causes, it is definitely likely that true scientific work time standards can be determined from a typical curve or the underlying mathematical model, statistically representing the performance time distribution under question.

Variation in performance.--The necessity for finding a mathematical model for a given task or tasks will be eliminated if all work is performed automatically by machines. But as long as a human being is performing the task, the performance time will be subject to variation. Interruptions of various kinds and inconsistencies in the speed of an operator's movements and in an operator following a given set of motions each time the task is performed, all cause a variation in the time required to perform any given task.

Research at the Georgia Institute of Technology has been conducted over the past five years investigating work-time patterns of variation for a short cycle, manual, repetitive, worker-controlled, assembly operation. A considerable amount of this work was limited because the data were gathered over a short period during a day or at the most two or three days. In other words, the sample sizes generally were small. Also, all of the work was based on the one short cycle operation.

It is the purpose of this presentation to attempt to substantiate the general results of this previous research, utilizing as a basis for study a longer cycle, manual, repetitive, worker-controlled, non-assembly type operation. To assure representative samples, every cycle performance time for a period of one week is used as the data for the investigation. This thesis should help shed some more light on the phenomena of the pattern, distribution, and stability of cycle performance times.

CHAPTER II

LITERATURE SRUVEY

Fatigue and work performance.—There is, at the present time, little knowledge concerning the pattern, distribution, and stability of rates of output under varied environmental conditions. Concerning this, Seashore believes that,

> . . . Motivational factors, the interest of the person in his work, and group morale are relevant. Usual neglect of, or special attention to, these factors might well alter the effectiveness of the worker, as was shown in the well known Western Electric experiment (9).

Many of the previous studies involved attempts to determine if there is any typical pattern into which a worker's production rates fall. Nearly all studies of curves of output have been conducted by psychologists in their investigations of that elusive concept called "fatigue." It is notable that the psychologists have been examining production rates, whereas the industrial engineers have been probing the phenomena of performance or production times. The evasiveness of a precise determination of fatigue led Muscio in 1921 to recommend, ". . . that the term fatigue be absolutely banished from precise scientific discussion, and consequently that attempts to obtain a fatigue test be abandoned" (10). In most cases, the work curve, resulting from a plot of production rates versus the time of the day, has been used as an indicator of the presence or lack of presence of fatigue.

The existence of a "typical fatigue curve," or decrement curve, has been adhered to for many years. This "typical curve" consisted of an early morning "warm-up" period, a gradual rise to a peak after about two hours, and a general decline until the lunch hour. The afternoon curve resembled the pre-lunch curve except that the peak was reached sooner after the commencement of work and was lower than the morning peak. This peak was followed by a general decline the remainder of the day (11). However, Rothe found that individual work curves varied considerably from day to day and that there was no "typical work curve" for an operator or for an operation (12).

Ryan, after studying various "typical patterns" resulting from a multitude of studies, asserted that,

> These examples are enough to indicate the state of affairs. Perhaps many jobs do show a bona-fide fatigue decrement toward the end of the day (a decrement which is not due to decreased motivation or to the worker having completed a quota which he has set for himself). Even if we grant that possibility, there are sufficient exceptions to the "typical pattern" to make it a doubtful index of fatigue. If the typical pattern appears, we still have difficulty in showing that the decrement is not the result of lowered motivation. If the typical pattern fails to appear, it cannot be taken as evidence of lack of fatigue. We can only say that the output criterion has failed as an indicator of variations in working capacity (13).

In their excellent collation of nearly all aspects of the problem of fatigue and impairment, Bartley and Chute added to Ryan's conclusion by stating that,

> Neither fatigue nor impairment can be measured by the work output of the intact organism. Activity may be used as a measure of impairment only when such systems as isolated nerve-muscle preparations are used. Work output is the primary interest in industrial studies of fatigue. This interest is natural, for it is not fatigue as such, but fatigue as it relates to production that is important to industry. Exclusive pre-occupation with disclosing relations between "working conditions" and output, nevertheless, represents a much aborted insight into the full situation. Work output must always be viewed in terms of conditions lying within the individual who is called upon to perform (14).

To explain the decrement phenomenon, Davis and Josselyn studied a manual, repetitive, worker-controlled, assembly type operation in which the production rate followd the "typical" work decrement pattern. They found that the "effective operation time," that part of the overall cycle time during which the operator performed only the motions contained in the standard work method, did not vary significantly throughout the day. Concerning manual, worker-controlled operations in general, they further hypothesized that, "The operator uses the same work method and continues to work at the same rate of speed whenever the operation is performed, but introduces more and longer work stoppages as the day progresses (15)." However, the results of Davis and Josselyn's study should be accepted with caution since they related little or no information concerning sample sizes used, groupings of data, or statistical tests and levels of significance employed in analyzing their data. Also, it is very difficult to understand how they arrived at an accurate effective operation time after analyzing their methods for gathering data.

One purpose of this presentation is to investigate work curves in a general manner. Cycle performance times, rather than output rates, are used in the analysis. The use of cycle times will produce curves which should bear an inverse relationship to output rate data.

Work-time distribution.--Wiberg suggested some interesting information in his analysis of the work-time distribution. A work-time distribution is a, " . . . frequency distribution of a specific number of work-times, obtained by means of time study on a series of elements in repetitive work" (16). Wiberg stated that the skew of the distribution relates to motivation, range and deviations to movement habits, and high and low minimum values relate to aptitude or lack of it (17). Wiberg's work is important because it is necessary to determine the characteristics of a formal distribution of a worker's cycle performance times in order to develop a mathematical basis for time study.

Current research.—Much of the research into performance time phenomena conducted during the past few years has refuted many of the basic concepts of time study that had previously been accepted without question. Some of the results are important because they appear to have produced evidence supporting work-time predictions through the use of techniques of statistical inference. It is notable that the impetus for most of the research was furnished by Gomberg (18).

Adam Abruzzi directed an investigation of performance times of manually controlled operations in the garment industry. Utilizing control charts and studying the patterns of variation of the work-times, he concluded that, "individual workers develop a relatively constant pattern of variability within samples" (19). He reached this conclusion because he found the ranges in control in nearly every case, even though there was a substantial variation in the mean cycle times. These findings led Abruzzi to hypothesize that workers adjust their work pace in terms of their individual abilities and needs and that the constant pattern of variation of workers is related to the work method rather than to pace (20).

Considerable other work has concerned itself with investigating and questioning the basic assumptions of the use of standard data, primarily pre-determined time systems with time data formulated in minute muscular reactions or therbligs. In recent years, the pre-determined time systems such as Methods-Time-Measurement (21), Work Factor (22), Basic Motion Timestudy (23), and the systems developed by Segur (24) and Holmes (25) have become increasingly more popular. One reason for their popularity is due to their elimination of the necessity to apply the subjective and most controversial rating factor. Also, all of the above systems claim universal application. The basic assumption present in all of the above systems is that when basic time study elements are assembled into the motions required to perform an operation, they constitute an independent additive set of elements. However, Barnes and Mundel found that individual therbligs in cycles were not independent of one another, being inter-related, after studying the time required to position pins in bushings (26). Similar studies conducted by Nadler and Wilkes (27) and Nadler and Denholm (28) illustrated that the addition or elimination of therbligs from an established motion pattern, significantly affected the original total cycle time and also the individual therblig times. However, these studies and the ones at Georgia Tech concerning elemental or therblig independence (29)(30) were based on short cycle operations where the motions involved consisted predominantly of an eye-hand coordinated movement. From the search of the literature, no reference could be found concerning the independence of elements of a long cycle operation where various body members such as trunk and legs enter into play.

At the Ohio State University, H. O. Davidson has been directing performance time research. One result has been the rejection of the previously held concept which assumed a Gaussian or normal distribution for worker performance times. A statistical evaluation of Barnes' original "normal" distribution (31) rejected the normal hypothesis and showed the sample distribution actually to be skewed (32). Davidson summarized that,

> The assumption of normal distribution of relative production rates of individual workers is operationally invalid. The development of any general rule for the statistical definitions of a normal worker should be approached with great caution (33).

Davidson also reported an investigation of three basic standard data systems by means of analytical statistics, after which he concluded that, " . . . differences among and between the Work Factor, M-T-M, and Holmes systems of standard data are so great that, if any one of them is accurate, the others definitely are not" (34).

After conducting exploratory studies of cycle time variations, Davidson suggested caution in drawing inferences and conclusions from control charts when performance time samples are small, because a false indication of lack of control is more likely to occur when applying a control chart analysis to a time study containing a large number of observations than when applying it to a study containing a small number (35). Davidson concluded his present work by doubting the existence of the constant chance cause concept in time study. However, he asserted,

> . . . that the constant chance cause concept as used in quality control is by no means the only basis upon which a scientific system of time study, or a "sub-scientific" system having practical validity, might be established. To find these bases we must look not to other fields to see what may be borrowed, but to research on the performance-time phenomena in order to find out what is needed (36).

Research at Georgia Institute of Technology.—Research on performance time phenomena was begun in the School of Industrial Engineering at the Georgia Institute of Technology in 1951 under the direction of Doctors R. N. Lehrer and J. J. Moder. The preliminary results have been published by them (37). The long range objective of the project was to study the mathematical characteristics of a short cycle, manual, worker-controlled, repetitive operation's performance times to determine a mathematical model for the work-time distribution. The short range objective was to investigate statistically workers' cycle performance time patterns of variation (38). The job selected for study was a short cycle, worker-controlled, manual, highly repetitive, assembly type operation.

Lind made the first study, which utilized stop watch time study methods to collect data. He analyzed the data in control charts and work-time histograms and concluded that, "The operator performance times formed a positively skewed distribution. The operator performance times lacked statistical stability in all except one case" (39).

Taft's study was next and, following Lind's recommendation, he made a micro-motion analysis of the same operation and operators as Lind (40). He investigated the effect on the cycle time distribution with identifiable assignable causes of variation intact and removed. Taft, too, noted positive skewness and found that the sample distributions approximated the log-normal curve with and without the cycles containing variations included (41).

Friedman then proceeded to determine a theoretical work-time distribution using the data gathered by Lind and Taft (42). Utilizing only stable operators, determined by control chart analysis and by an analysis of variance between and within samples, Friedman reached the conclusion that the theoretical distribution for stable operators appeared to have the following characteristics:

1. It differs significantly from the normal curve.
2. It is positively skewed.
3. Its peakedness is greater than that of the normal curve.
4. It can be reasonably approximated by a Pearson Type III curve (43).

McLeod, at the same time, investigated the statistical stability of performance times, with and without assignable causes of variation removed, utilizing Taft's film data. He concluded that removal of assignable causes of variation, as identified in the film study, did not necessarily cause the instability indicated by the control charts (44). In his discussion of the results of his investigation, McLeod stated that, " . . . unnecessarily strict control of these performance times, which infers control upon certain personal motivations, may be neither scientifically achievable nor sociologically feasible" (45). One of his recommendations for future study, which is along the same lines as Davidson's conclusions, suggested an evaluation of the aptness of strict adherence to the techniques and disciplines of statistical quality control when dealing with work performance times regarding, particularly, the significance of runs and trends (46).

Summers completed a later study using Taft's data and the data as modified by McLeod. He found from his investigation that cycle time stability does not significantly affect the mean time, skewness, or peakedness of the work-time distribution, but that it does influence the variance or dispersion of the distribution (47). He also found little relationship between stability and the goodness of fit for the Normal, Log-Normal, and Pearson Type III curves. Finally, Summers concluded that the typical curve for the operation studied is not necessarily one of those mentioned above, but may be another curve having both a constant skewness and peakedness and that the variance of this curve will be the only independent parameter influencing its shape (48).

The two latest investigations were conducted by Muse (49) and Rogers (50). Both used, as a basis for analysis, the short cycle operation studied previously at Georgia Tech. However, both used large sample sizes. The data were gathered utilizing a milli-minute timing device developed by the Clary Corporation and described in detail in the thesis by Rogers.

Muse's study was concerned with the effects of motivation on the work-time distribution. Muse assumed that the long term mean of the cycle times would be indicative of the degree of motivation of the operator. His results showed that there was no significant correlation between the mean and the skewness, the mean and the peakedness, and the mean and the standard deviation of the work-time distributions of the operator studied (51). Muse in his conclusions questioned the use of the mean of the cycle times as a reliable indicator of the degree of motivation.

Rogers' investigation had a two-fold purpose. The first was to determine the general nature of the parameters of work-time frequency distributions derived from sample sizes greater than five hundred and to compare the results with previous research. The second was to determine the nature of the parameters of delay-time distributions and to compare the results with the work-time distributions obtained. His results substantiated the previous work in the analysis of the characteristics of work-time distributions (52). Within the limitations of the small sample sizes which made up the delay distributions, the measures of skewness and peakedness did not differ significantly from the normal curve (53).

Among Rogers' recommendations for future study were the suggestions to select an operation having a longer cycle time and to observe the operator's performance throughout a complete work day or shift (54). These suggestions were incorporated into this present study and were expanded to the extent that data were gathered over a complete week for each of two operators.

The three principal limitations of the previous studies were that the investigations covered only one operation in one plant, the data represented only a limited number of operators, and the data were collected over short periods of time. This presentation and the current thesis study by Cecil G. Johnson, a graduate student at Georgia Institute of Technology, should help overcome these obstacles.

The purpose of Johnson's investigation is to substantiate, in a general manner, the previous work in the analysis of work-time distributions. For his analysis, Johnson has gathered industrial time study data from several different operations having many different mean cycle times. Preliminary results indicate an essential agreement with the findings of previous research.

Conclusion.—From the examination of the literature, it is seen that there is still a vital need for basic and applied research in the field of work measurement. In the short range view it should be clearly recognized that practical problems exist which must be solved by some means, scientific or not. However, for time study to be considered a science, a considerable amount of basic research must be performed. This research can result in valid scientific concepts that will contribute greatly to provide better techniques and better solutions to our practical problems.

CHAPTER III

OBJECTIVES

Much work has been accomplished concerning the work-time patterns of workers. Yet, the knowledge pertaining to the patterns, distributions, and stability of cycle performance times of operators is still inadequate. There is much more work to do if theoretical work curves for all operators for various types of tasks are to be derived.

The general purpose of this study was to investigate the pattern of variation of an operator's cycle performance times over several days in order to help further develop time study into a truly scientific area of endeavor. This presentation expanded certain portions of the previous research at Georgia Tech to the extent that a longer cycle, manual, worker-controlled, repetitive, non-assembly type operation was observed for an entire week for each of two operators.

The first specific objective of this study was to determine what, if any, evidence there is of a linear trend in the work-times over a period of each half-day, full day, and week based on samples of cycle times with all assignable causes of variation remaining within the cycle time, and based on samples in which the time consumed by the assignable causes of variation has been subtracted out of the total cycle time.

The second objective was to determine if the cycle times exhibited a pattern of random variation over a period of five days.

The third objective was to determine if there was any similarity between the results of previous research at Georgia Tech based on samples from a short cycle, manual, worker-controlled, repetitive, assembly type operation, and the measures of skewness and peakedness based on samples, with and without assignable causes of variation intact, from a longer cycle, manual, worker-controlled, repetitive, non-assembly type operation.

The fourth objective was to determine if the mean and variance of the work-time distribution of cycle times, with and without assignable causes of variation intact, for any half-day or daily period were significantly different from the mean and variance of the work-time distribution of cycle times, with and without assignable causes of variation intact, for any other half-day or daily period.

CHAPTER IV

PROCEDURE

The procedure basically involved two main steps. The first was the preparation, which included the selection of the operation and operators, the gathering of the data, and the translating of the data into useable forms. This step will be discussed in this chapter. The second step concerned the application of various statistical techniques and will be discussed at length in Chapter V.

Selection of the operation.—To select a job that would be representative of a long cycle, manual, worker-controlled, repetitive, assembly or non-assembly type operation entailed an extensive survey of various industries in the area of Atlanta, Georgia. An industrial situation was desired because doubt has been expressed as to the validity of studies of this type conducted wholly within the laboratory (55), and because it is the policy of the Industrial Engineering Department at Georgia Institute of Technology for whom this investigation was made, to have research done in industrial situations whenever possible. This, however, poses certain limitations and problems, for in an experimental study it is possible to control many variables such as time, working conditions, work method, supply of materials, and others, whereas in an industrial study this is usually impossible and the investigator can only observe and describe the conditions. The latter was true of this study.

Snow's Laundry and Dry Cleaning establishment in East Point, Georgia had an operation which fitted most closely the requirements described previously. The operation selected was one of the steps in the process of laundering cotton shirts. The over-all process was made up of the following principal steps:

1. Pick-up of dirty laundry by truck from branch outlets.
2. Separation of shirts from other laundry.
3. Identification marking of shirts.
4. Washing of shirts by lots.
5. Damp-drying of the shirts.
6. Pressing, inspecting, and folding of shirts.
7. Grouping of shirts with other laundered items.
8. Delivery of finished laundry to branch outlets.

The shirt pressing sub-operation of the sixth process step was chosen as the specific operation to be investigated. All of the operators performing this sub-operation followed, basically, a standard sequence of motions, although there was some variation in the sequence order among operators. This was not true of the sleeve pressing, inspecting, and folding sub-operation of the same process step. Careful observation also revealed that the operators performing the shirt pressing sub-operation set the pace for this process step, as it had the longest cycle time of the two stages comprising the step. The operators investigated worked constantly at this one operation.

<u>Description of operation</u>.--The overall operation was performed by operators working in groups of two. A brief description of the first operator's task

is given below. To assist the reader in visualizing the operating area and the various positions of the operators and equipment, a layout diagram can be found in Appendix A.

1. Grasp damp-dry shirt and place one sleeve on fixture in sleeve press, close press.
2. Move to shirt folder, grasp shirt off finished stake and position in shirt folder.
3. Return to sleeve press, open press, remove shirt, place second sleeve on fixture, close press.
4. Move to shirt folder, place inserts, fold shirt, place in finished shirt rack.
5. Return to sleeve press, open press, aside shirt with sleeves pressed to intermediate stake.

However, the above steps were not necessarily performed in the order given. This operator always performed her task so as to have at least one partially finished shirt on the intermediate stake. The second operation, which consisted of pressing the remainder of the shirt, was the one selected for study. A complete description of the operation can be found in Appendix A, but a short account is presented below. For purposes of clarity, it is noted that there were three shirts in process at all times.

1. Grasp shirt off intermediate stake with left hand, open press No. 1, aside shirt in press with right hand to shelf between presses Nos. 1 and 2, place shirt in left hand in press to press collar and cuffs, close press No. 1.
2. Move to press No. 2, open press, remove shirt from press, position and place same shirt to press one-half of back of shirt, close press, wait.

3. Open press No. 2, move shirt in press over to press second-half of back, close press.
4. Grasp shirt (asided in step one above) from shelf with left hand, wait, open press No. 2, aside finished shirt with right hand to finished stake, place shirt in left hand in press to press front, close press No. 2.
5. Move to finished stake, button top button of shirt on finished stake, move to press No. 1.
6. Open press No. 1, remove shirt and place same shirt back in press to press yoke (upper back section of shirt), close press, reach for shirt on intermediate stake.

Operation end points.--From observation of the operators, the natural end point was at the end of the sixth element. Most operators would stop at this point if they wished to rest, take a drink, light a cigarette, go to the rest room, etc. Nevertheless, as each press always contained a shirt, operators would sometimes stop for short periods after all of the above elements. Work stoppages occurred infrequently within the elements. Properly, all cycle times were recorded at the point where the operator's left hand touched the shirt on the intermediate stake.

Conditions of the investigation.--The study was made in the shirt and trouser pressing section of the laundry. The operators performing the shirt pressing operation were all Negro women, and were regular employees of the laundry. Five stations were available to accomplish the operation, although only four were in use during the periods the observer was present. The hours of work were from 8:00 A.M. to 5:00 P.M. on Monday through

Friday with a lunch period from 12:00 N. to 12:45 P.M. Total working time was eight hours and fifteen minutes although the operators rarely commenced or completed production according to the above schedule. There were no official rest periods. However, conversation, smoking, and work stoppages of various kinds could take place at the discretion of the operators. The operators procured their own supply of damp-dry shirts, so a rest period usually occurred when their supply of shirts was depleted. The operators did not usually know, on any day, how late they would work that afternoon until approximately 2:00 P.M. when the delivery truck arrived with laundry from branch stations. A table of the actual amount of time the observed operators worked each day during the observation period with the number of units of production accomplished is contained in Appendix A.

The wages paid the operators were about average as compared to similar jobs in the laundry industry in the Atlanta area. Motivation was judged to be about average, neither high nor low, even though incentives were paid. However, it is important to note that the reason for this "average" or non-noticeable motivation probably lay in the plan itself. The operators were paid a straight hourly rate for the time they were in the shop, excluding the lunch period. They were also paid a small incentive rate for the average amount of work accomplished over standard, based on the total time they were in the shop on that particular day. The standard was forty-four shirts per station per hour and was last set in 1946. This standard was easily exceeded by all operators when there was a large number of shirts being processed. Because of the "irregular" supply of shirts, an operator could, many times, earn more wages by slowing down in the performance of her work than if she performed at a rapid pace and finished early in the afternoon. It was rather difficult for an operator to determine which course would result in the largest financial return. Conversation with the workers revealed that none of them took the trouble to figure the alternatives even when they knew exactly how many shirts remained to be processed on a particular day.

Readings of temperature and relative humidity were taken several times during the study from permanent gages in the laundry. In general, the temperature varied between 60 degrees and 80 degrees Fahrenheit and the relative humidity varied between 50 percent and 65 percent. There was sufficient lighting, good ventilation, and the work area was moderately clean. One white female was responsible as supervisor for the entire shirt and trouser finishing section.

Selection of operators.—It was the original intent of this investigation to analyze the data gathered from observing one operator for a two week period. Yet, due to the placement of a third operator at the station being observed, it became necessary to select another operator to study. Of the four operators available for study, two were selected. They were not chosen by the use of any tests, but were selected after consultation with the plant manager, supervisor of the section, and the workers. Both operators selected for observation were well experienced. Operator A, the operator observed during the first week, had two years' experience as a shirt presser and a "fair" production record. Operator B, the operator observed the second week, had ten years' experience and a "good" production record. Operators A and B were twenty-four and forty-one years of age, respectively. Both were of a fairly low educational level.

Preliminary film investigation.—To enable the observer to familiarize himself with the various aspects of the cycle, an extensive preliminary investigation of the operation was made. One hundred feet of film were exposed at the rate of 1000 frames per minute in order to determine the basic standard motion patterns involved in the operation. As this film contained only five complete cycles, another one hundred feet were exposed with a time-lapse camera at the rate of 100 frames per minute. This time-lapse film contained forty complete cycles and enabled the observer to determine the various delays and assignable causes of variation that were likely to occur in the operation.

Assignable causes of variation.—Variables were classified as assignable causes of variation if they were not likely to occur in every cycle. Careful analysis of the film samples and of the actual operation disclosed numerous departures from the standard method. All identifiable delays and variations occurring between the end of the sixth element and the beginning of the first element, as defined in the operation description, were grouped and timed as external delays. No further use was made of these external delay times in the study. Identifiable internal sources of variation were of the three main types as follows:

1. Worker controlled variations having no direct relationship to the operation. These included stoppages for personal reasons such as stoppages to clean glasses, stoppages to talk, drink, or smoke, trips to the rest room, etc.
2. Worker controlled variations having a direct relationship to the operation. These included buttoning the top button

on a finished shirt, wetting a shirt with a water spray gun before pressing, repeat pressing of a shirt not pressed correctly the first time, stopping and holding up a shirt to inspect it, variation in the sequence of motions involved in the operation, etc.

3. Variations over which the operator had no control which bore a direct relationship to the operation. These included press breakdowns, short sleeve shirts which eliminated part of the cycle, interruptions by supervisors, etc.

Accurate rapid detection of the beginning and ending points of the various internal and external variations required a considerable amount of practice on the part of the observer. In order to decrease reaction time inaccuracies, classification of variations were condensed into four types:

External: 1. Variations between cycles.

Internal: 2. The element consisting of buttoning the top button of the shirt.

3. Wetting the shirt.

4. All other variations within cycles.

Also, all cycles containing unusual shirts, such as short sleeve shirts, and all cycles containing variations in the sequence of motions involved in the operation were noted.

Other uncontrollable variables were present in this investigation (this study is properly spoken of as an investigation and not an experiment). The following uncontrolled sources of variation may be briefly noted: inaccuracies in timing, degree of dampness of the shirts, texture, weight, and size of the shirts, age, experience, and private lives of the operators, illumination, humidity, undetectable variations in the method used by the operators, effects of the wage payment plan, psychological and physiological factors such as muscular impairment, boredom, monotony, and the presence of the observer. The influence and effects of any and all of these factors can only be surmised.

General method of gathering data.—As mentioned previously in Chapter II, one of the most pronounced limitations of previous research in the particular area of time study under discussion has been the relatively small sample sizes from which statistical inferences were to be drawn. For that reason, it was the purpose of this study to collect data on two operators for one week periods each, observing every cycle time.

In order to eliminate any variation between observers, all observations were recorded. This, however, posed a problem in gathering the data, as the long hours spent in collecting data would be definitely tiring to the observer and inaccuracies might creep into the data. Various methods were considered for gathering the data. The use of micro-motion or kymograph techniques were dropped from consideration because they would have resulted in a prohibitive cost in money and time required for analysis. Conventional stop-watch time study techniques were considered but cycle times could only be recorded to the nearest hundredth of a minute and stop-watch timing has certain inherent variables and inaccuracies which might affect the study. It was decided to use the Clary milli-minute timing machine used by Muse and Rogers to gather the large sample sizes of data analyzed in their work. This machine recorded time to the nearest 0.001 minute. However, after several weeks of attempting to collect data with the device, interspaced by frequent trips with the machine to the repair shops, it became apparent that the Clary timer was unreliable. Mechanical and electronic malfunctioning of the instrument became a habitual occurrence.

It then was necessary to utilize the methods of stop-watch time study. A split-hand decimal minute stop watch was used with the continuous method of timing. A split-hand watch was used so the observer could always read a motionless hand and thereby increase the accuracy of the recordings. The duration of each cycle time and the time for the four types of variations, described previously in this chapter, were recorded along with other items of interest. Although the observer was already thoroughly familiar with the operation, an additional twelve hours were spent attaining proficiency with the stop-watch method of timing. Because of the above preliminaries, the writer was confident that the data collected were not significantly different from the data that would have been gathered utilizing the Clary machine. The observation periods for each operator for each day are contained in Appendix A.

CHAPTER V

METHOD OF ANALYSIS

Tabulation.—The data were tabulated into two frequency distributions for each half-day period for each operator. These distributions were:

1. Distributions of raw cycle time frequencies, hereafter called the total cycle time distributions, and
2. Distributions of cycle time frequencies remaining when all cycle times containing variations in the sequence of motions, short sleeve shirts, and unusual shirts had been removed and the time consumed by internal delays had been subtracted from the remaining individual cycle times, hereafter called the "modified cycle time distributions."

The latter distributions were formed as described because the practice of removing cycle times containing internal delays to form modified cycle time distributions as was exercised in past research would have reduced the data beyond the point where statistical inferences could be made. Also, the data gathered on each operator's performance were evaluated separately because of the vast differences in the method and resulting cycle times employed by each operator.

The half-day distributions were combined to get grand weekly modified and total cycle time distributions for each operator. Illustrations of frequency histograms of these distributions may be found in Appendix B, Figures 3-14.

Moments.—The following estimates of parameters were obtained for each of the distributions described:

Mean — $\bar{X}$

Standard Deviation — s

Measure of Skewness — g_1

Measure of Peakedness — g_2

Coefficient of Variation — va

These were computed by the I.B.M. 650 Electronic Data Processing Machine at the Rich Electronic Computer Center according to the following equations:

x_i — the ith observation of the period or distribution

n — the total number of observations in the period

m_2 — 2nd central moment

m_3 — 3rd central moment

m_4 — 4th central moment

V_1 — 1st basic moment — sum of $\frac{x_i}{n}$

V_2 — 2nd basic moment — sum of $\frac{x_i^2}{n}$

V_3 — 3rd basic moment — sum of $\frac{x_i^3}{n}$

V_4 — 4th basic moment — sum of $\frac{x_i^4}{n}$

$$\bar{X} = V_1$$

$$m_2 = V_2 - (V_1)^2$$

$$s = (m_2)^{\frac{1}{2}}$$

$$m_3 = V_3 - 3V_2V_1 + 2(V_1)^3$$

$$g_1 = m_3/(s)^3$$

$$m_4 = v_4 - 4v_3v_1 + 6v_2(v_1)^2 - 3(v_1)^4$$
$$g_2 = m_4/(m_2)^2$$
$$va = s/\bar{X} \times 100$$

These measurements were computed for the forty half-day distributions by the I.B.M. 650 data processing machine. Sums and sums of squares of cycle times for half-day periods were computed by the machine and the results were combined by use of a hand computer to derive the mean, standard deviation, and coefficient of variation of the daily and weekly periods for modified and total cycle time distributions for each operator. Tables of all the estimates of the parameters of the distributions may be found in Chapter VI, tables 1-2.

Trend.--A least-squares linear trend line was established for the modified and total cycle times of each operator for each half-day, daily, and weekly period. The values for a and b in the following equation were computed by the I.B.M. 650 data processing machine:

$$x = a + bt$$

where $t = 1, 2, 3, ----, n$ and n was the total number of observations in the period analyzed. Illustrations of these trend lines may be found in Appendix C, Figures 35-38, and the equations of the linear trend lines can be found in Appendix C, Table 19.

Random Variation.--To detect gradual changes in the level of performance of an operator, run tests were performed for half-day periods on modified cycle times for both operators according to the procedure outlined by Hald (56).

Due to the nature of the data, the results were not necessarily conclusive, and a test based on the mean square successive differences was used to detect fluctuations in the level of performance and cyclical movements. The mean square successive differences were computed by the I.M.B. 650 data processing machine for the modified and total cycle times of each operator for half-day, daily, and weekly periods using the following formula:

$$q^2 = \frac{\sum(X_i - 1 - X_i)^2}{2(N - 1)}$$

Hald has shown that the ratio of the mean square successive difference to the over-all variance of a period is approximately normally distributed for N greater than twenty (57) so that:

$$z = (r-1) \sqrt{N + 1}$$

where z is the normal standard deviate and $r = q^2/s^2$. The significance of these ratios may be found in Chapter VI, Tables 3-4.

To further analyze for trends and to detect observations outside of statistical control limits, control charts were constructed for each half-day period of the modified and total cycle times of each operator. These charts may be found in Appendix B, Figures 15-34. All cycle times occurring in a period were plotted on the charts. The black dots indicate cycles containing variations in the sequence of motions, short sleeve shirts, and unusual shirts. The cycle times represented by the black dots on the modified cycle time charts were not used in determining their control limits. Breaks in the lines connecting the cycle times indicate delays between cycles.

In determining control limits for the half-day periods, an assumption was made that the modified and total cycle time distributions of each period could be typified by a Pearson Type III curve. This resulted from observation of the moments, of the histograms, and of the results of testing the third and fourth moments of each half-day distribution for normality. Accordingly, normal control limits were plotted for each distribution and Pearson Type III limits were determined and plotted for each distribution that was significantly different from normal at the ninety-five percent confidence level using the tables derived by Salvosa (58).

Tests on Mean and Variance of Distributions.--A test designed by M. S. Bartlett (59) was run on the variances of the half-day modified and total cycle time distributions for each operator to examine for homogeneity of the variances within each of the four sets of ten variances using the formula:

$$X^2 = \frac{2.3026}{c}\left(f \text{ Log } s^2 - \sum^{k} f_i \text{ Log } s_i^2\right)$$

with k - 1 degrees of freedom

where s^2 = the pooled k empirical variances

f = degrees of freedom of s^2

s_i^2 = an empirical variance of the ith half-day period

f_i = degrees of freedom of s_i^2

$$c = 1 + \frac{1}{3(k-1)}\left(\sum^{k} \frac{1}{f_i} - \frac{1}{f}\right)$$

The results of these tests may be found in Chapter VI, Table 5.

Next, an analysis of variance was made on the modified and total cycle time distribution means for each operator using the procedure outlined by Hald (60). A one-way classification utilizing multi-stage grouping was used with a model equation as follows:

$$X_{ijk} = m + A_i + A_{ij} + A_{ijk}$$

The daily mean, $m + A_i$, and the half-day mean, $m + A_i + A_{ij}$, were systematic components or Model I variables, while the A_{ijk} term was a stochastic variable in the analyses. The results of these analyses are shown in Chapter VI, Table 6.

As the population means and variances within each second order grouping were significantly different, it became necessary to determine how they differed. To examine the means, ninety-five percent confidence intervals for each operator for modified and total cycle time distributions were established according to the formula:

$$\bar{X} - z\frac{s}{(n)^{\frac{1}{2}}} < m < \bar{X} + z\frac{s}{(n)^{\frac{1}{2}}}$$

where $z = 1.96$ and m is the population mean. These confidence intervals can be found in Chapter VI, Tables 7-8.

The means of the modified and total cycle time distributions for each operator for each half-day period were then tested against the means of the full weekly distributions at the 0.05 level of significance using the following formula:

$$z = \frac{\bar{X} - m}{s/(n)^{\frac{1}{2}}}$$

where m equaled 0.91122 and 0.77287 for the total and modified cycle time distributions respectively for Operator A and 0.87464 and 0.74048 for the total and modified cycle time distributions respectively for Operator B. The results of these tests may be found in Chapter VI, Table 9.

As these results did not necessarily indicate the day to day shift in performance and the shift between morning and afternoon periods, it became essential to test each operator's daily means against each other daily mean and to test each operator's morning mean against the afternoon mean. This was done using the formula:

$$Z = \frac{\bar{X}_1 - \bar{X}_2}{\left(\frac{(s_1)^2}{n_1} + \frac{(s_2)^2}{n_2}\right)^{\frac{1}{2}}}$$

where z is the normal standard deviate. The significance of these tests may be found in Chapter VI, Tables 10-11.

Although there was some doubt as to the rigor of the test, a similar test was performed on the half-day means using the Multiple Range techniques developed by D. B. Duncan (61). However, the test showed similar results to the previous tests at the 0.05 level of significance.

To examine the differences between the standard deviations of each operator, ninety-five percent confidence intervals were established for half-day and weekly periods of both modified and total cycle time distributions according to the formula:

$$s - z\frac{s}{(2n)^{\frac{1}{2}}} < \sigma < s + z\frac{s}{(2n)^{\frac{1}{2}}}$$

where $z = 1.96$. These confidence intervals are complied in Chapter VI, Tables 12-13.

These results, also, did not necessarily indicate the significance of variation in day to day performance and morning and afternoon performance. It became necessary to test each operator's morning standard deviation against the afternoon standard deviation and to test each daily standard deviation against each other daily standard deviation. This was accomplished using the Fisher test:

$$F = \frac{(s_1)^2}{(s_2)^2}$$

F being determined by the respective degrees of freedom for the variances being tested. The results of these tests may be found in Chapter VI, Tables 14-15.

<u>Tests for Normality</u>.—The estimates of the parameters of skewness (g_1) and peakedness (g_2) for half-day periods of the modified and total cycle time distributions for each operator were tested for normality using the tables derived by Geary and Pearson (62). These tests were made to compare the results with the findings of previous research at Georgia Tech. All values of g_1 and g_2 were tested at the 0.05 level of significance and the results of the tests can be found in Chapter VI, Tables 16-17.

CHAPTER VI

RESULTS

Parameters.—The estimates of the parameters of the modified and total cycle time distributions were tabulated as shown in Tables 1-2 and no distinct pattern of variation of the statistics was discernable. However, some indications of a pattern were present. The means of the modified and total cycle time distributions for both Operator A and B for half-day periods were generally lower in the afternoon than in the morning except for Monday and Tuesday for Operator A. Also, the means of the daily periods were usually highest on Mondays and Fridays with lows on Wednesday. This suggests the presence of the so called "week-end effect" on the operators. The "pattern" of the standard deviations was the same as that of the corresponding means except that the "pattern" for the daily standard deviations was reversed for the modified cycle time distributions for Operator B. Generally speaking, the standard deviations varied directly with the means. This substantiates the previous results found from research at Georgia Tech.

Another notable result from the analysis of the statistics was the small range of the coefficients of variation of the distributions. Operator A's total and modified cycle time distributions for half-day and daily periods for a week had a range of 7.9% and 5.5% respectively for the total cycle distributions and a range of 2.2% and 3.1% respectively for the modified cycle distributions. The more experienced

Table 1. Estimates of Parameters for Distributions
Operator A

Period	N	$\bar{X}$ Mean	S Std. Dev.	g_1 Skewness	g_2 Peakedness	va Coef. Var.
			Total Cycle Distributions			
Mon.-AM	146	1.00938	0.18354	1.788	7.062	18.2
PM	130	0.92561	0.11753	2.058	10.597	12.7
Tue.-AM	228	0.91908	0.11028	1.457	7.363	12.0
PM	263	0.91256	0.10838	0.793	3.606	11.9
Wed.-AM	224	0.90031	0.10334	0.723	4.199	11.5
PM	270	0.85485	0.08767	0.669	4.196	10.3
Thu.-AM	216	0.89796	0.12971	1.880	10.570	14.4
PM	277	0.89534	0.10395	1.154	5.789	11.6
Fri.-AM	193	0.95451	0.14775	1.227	6.799	15.5
PM	147	0.90537	0.12340	1.764	7.915	13.6
Mon.	276	0.96993	0.16186			16.7
Tue.	491	0.91373	0.11705			12.8
Wed.	494	0.87547	0.09788			11.2
Thu.	493	0.89649	0.11619			12.9
Fri.	340	0.93326	0.14036			15.0
Week	2094	0.91122	0.12689			13.9
			Modified Cycle Distributions			
Mon.-AM	125	0.83624	0.07489	0.229	2.556	9.0
PM	107	0.80037	0.06951	0.473	2.703	8.7
Tue.-AM	186	0.76129	0.06059	0.233	2.552	8.0
PM	223	0.77633	0.06794	0.275	2.652	8.7
Wed.-AM	202	0.77619	0.07204	0.395	2.981	9.3
PM	250	0.73672	0.06234	0.718	3.740	8.5
Thu.-AM	174	0.76236	0.06727	0.508	2.979	8.8
PM	226	0.76234	0.05371	0.355	3.219	7.1
Fri.-AM	150	0.80400	0.07225	0.294	2.650	9.0
PM	135	0.77274	0.06755	0.525	2.785	8.7
Mon.	232	0.81970	0.07476			9.1
Tue.	409	0.76570	0.08438			11.0
Wed.	452	0.75436	0.06971			9.2
Thu.	400	0.76235	0.06008			7.9
Fri.	285	0.78919	0.07190			9.1
Week	1778	0.77287	0.07543			9.8

Table 2. Estimates of Parameters for Distributions
Operator B

Period	N	$\bar{X}$ Mean	S Std. Dev.	g_1 Skewness	g_2 Peakedness	va Coef. Var.
			Total Cycle Distributions			
Mon.-AM	220	0.89941	0.09256	1.269	5.725	10.3
PM	188	0.93117	0.12484	1.768	10.097	13.4
Tue.-AM	204	0.88142	0.09091	0.935	4.681	10.3
PM	241	0.91871	0.12241	2.479	15.408	13.4
Wed.-AM	250	0.86148	0.10680	1.982	9.759	12.4
PM	249	0.83558	0.10381	0.853	5.684	12.4
Thu.-AM	250	0.87472	0.10183	1.383	6.283	11.6
PM	221	0.85923	0.09629	1.286	7.211	11.2
Fri.-AM	252	0.86345	0.10792	1.650	9.752	12.5
PM	288	0.84385	0.08703	1.553	7.690	10.3
Mon.	408	0.91404	0.11045			12.1
Tue.	445	0.90162	0.11091			12.3
Wed.	499	0.84856	0.10630			12.7
Thu.	471	0.86745	0.09970			11.5
Fri.	540	0.85300	0.09793			11.5
Week	2363	0.87464	0.10770			12.3
			Modified Cycle Distributions			
Mon.-AM	215	0.76279	0.05611	0.287	3.208	7.4
PM	157	0.77649	0.06128	0.280	2.524	7.9
Tue.-AM	182	0.76451	0.05623	0.159	2.970	7.4
PM	182	0.77159	0.05922	0.074	3.041	7.7
Wed.-AM	194	0.73340	0.05529	0.343	2.794	7.5
PM	169	0.70455	0.04842	0.652	3.404	6.9
Thu.-AM	218	0.75110	0.05437	0.207	2.974	7.2
PM	199	0.73307	0.05750	0.582	3.249	7.8
Fri.-AM	199	0.71949	0.05844	0.361	3.021	8.1
PM	255	0.70239	0.05046	0.321	2.942	7.2
Mon.	372	0.76858	0.05882			7.7
Tue.	364	0.76805	0.05796			7.5
Wed.	363	0.71997	0.06277			8.7
Thu.	417	0.74249	0.06033			8.1
Fri.	454	0.70989	0.05486			7.7
Week	1970	0.74048	0.06140			8.3

operator of the two, Operator B, had a range of 3.1% and 1.2% for the half-day and daily periods respectively for the total cycle distributions and a range of 1.2% for both the half-day and daily periods for the modified cycle distributions. This is in contrast to the relatively wide range of the coefficients of variation found in the previous research and it indicates strongly the direct relationship between the mean and the standard deviation.

Trend.—The results of the linear trend analysis were not conclusive. The drawings shown in Appendix C, Figures 35-38, were exaggerated to illustrate the small amount of trend that did exist. An analysis of the figures and of the equations of the linear trend line equations in Appendix C, Table 19, revealed no significant pattern. A majority of the trend lines for half-day periods had a negative slope while only about half of the trend lines for daily periods had a negative slope as did the trend lines of the full weekly periods. However, the trend lines for the full weekly periods were nearly horizontal lines. Due to the nature and accuracy of the data, no inferences could be drawn that any of the trend lines were other than horizontal. Nevertheless, it is to be noted that trend lines other than linear utilizing higher polynomials might show a pattern for a worker's performance times.

Random Variation.—The various tests utilized to analyze for random variation of the cycle times for various periods also were inconclusive, but some definite indications of stochastic variation were present. The run tests on the modified cycle time series for half-day periods for Operators A and B showed that five of ten half-day periods for Operator

A and nine of ten half-day periods for Operator B were significantly different from a time series illustrating random variation at the five percent confidence level. These results have little meaning however, since a difference or error of 0.01 minute in certain cycle times of the runs analyzed would have resulted in all of the time series showing no significant difference from random variation. This point illustrates the weakness of the use of run tests in analyzing an operation's cycle times.

Tests utilizing the ratio of the mean square successive differences to the overall variance were made at the five percent confidence level. For Operator A, five of the ten half-day, three of the five full day, and the one full week periods of total cycle time series were significantly different from a series illustrating random variation. For the modified cycles of Operator A, six of the ten half-day, three of the five full day, and the one full week periods were significantly different from normal random variation. For the total cycles of Operator B, three of the ten half-day and four of the five full day periods were significantly different from normal random variation. And for the modified cycles of Operator B, six of the ten half-day, all of the five full day, and the one full week periods were significantly different from a time series exhibiting random variation. The significance of the ratios can be observed in Tables 3-4.

Control charts with Normal and Pearson Type III limits were constructed to further analyze for trends and to observe whether the distributions were in a state of statistical control. These charts may be observed in Appendix B, Figures 15-34. The results showed that the use of Pearson Type III limits added little or nothing to the state of

Table 3. Significance of the Ratio of the Mean Square Successive Differences to the Overall Variance of Half-Day, Daily, and Weekly Distributions for Operator A

Period	N	r Value	z Value	Level of Significance
		Total Cycle Distributions		
Mon.-AM	146	1.035	0.424	.20
PM	130	1.237	2.713	.01
Tue.-AM	228	0.901	1.498	.20
PM	263	0.953	0.764	.20
Wed.-AM	224	1.220	3.300	.001
PM	270	0.826	2.864	.01
Thu.-AM	218	0.746	3.742	.001
PM	277	1.079	1.317	.20
Fri.-AM	193	0.883	1.630	.20
PM	147	0.802	2.409	.02
Mon.	276	1.042	0.699	.20
Tue.	491	0.810	4.214	.0001
Wed.	494	1.045	1.001	.20
Thu.	493	0.893	2.378	.02
Fri.	340	0.868	2.438	.02
Week	2094	0.931	3.158	.002
		Modified Cycle Distributions		
Mon.-AM	125	1.427	4.793	.00001
PM	107	1.419	4.354	.0001
Tue.-AM	186	0.975	0.342	.20
PM	223	1.081	1.212	.20
Wed.-AM	202	1.199	2.835	.01
PM	250	1.083	1.315	.20
Thu.-AM	174	0.885	1.521	.20
PM	226	1.341	5.138	.000001
Fri.-AM	150	0.810	2.335	.02
PM	135	1.173	2.018	.05
Mon.	232	1.572	8.731	.000001
Tue.	409	0.610	7.897	.000001
Wed.	452	1.147	3.129	.002
Thu.	400	1.090	1.802	.10
Fri.	285	0.924	1.285	.20
Week	1778	1.053	2.235	.05

Table 4. Significance of the Ratio of the Mean Square Successive Differences to the Overall Variance of Half-Day, Daily, and Weekly Distributions for Operator B

Period	N	r Value	z Value	Level of Significance
		Total Cycle Distributions		
Mon.-AM	220	0.943	0.847	.20
PM	188	1.032	0.440	.20
Tue.-AM	204	0.883	1.675	.10
PM	241	0.863	2.131	.05
Wed.-AM	250	1.090	1.426	.20
PM	249	1.113	1.787	.10
Thu.-AM	250	1.038	0.602	.20
PM	221	1.170	2.533	.02
Fri.-AM	252	0.986	0.223	.20
PM	288	0.814	3.162	.002
Mon.	408	1.081	1.638	.20
Tue.	444	0.841	3.354	.001
Wed.	499	1.177	3.958	.0001
Thu.	471	1.173	3.759	.001
Fri.	540	0.900	2.326	.02
Week	2363	1.037	1.799	.10
		Modified Cycle Distributions		
Mon.-AM	215	1.195	2.866	.01
PM	157	1.168	2.112	.05
Tue.-AM	182	1.085	1.150	.20
PM	182	1.087	1.177	.20
Wed.-AM	194	1.312	4.357	.0001
PM	169	1.559	7.288	.000001
Thu.-AM	218	1.260	3.848	.001
PM	199	1.277	3.917	.0001
Fri.-AM	199	0.992	0.113	.20
PM	255	0.996	0.064	.20
Mon.	372	1.416	8.034	.000001
Tue.	364	1.234	4.471	.00001
Wed.	363	1.604	11.524	.000001
Thu.	417	1.763	15.600	.000001
Fri.	454	1.102	2.176	.05
Week	1970	1.305	13.540	.000001

statistical control because all total cycle time periods for both Operators A and B had numerous points above and below the Type III limits. There were no points below the lower Normal limits for the total and modified cycle distributions for Operators A and B, but all had points above the upper Normal limits for total cycle distributions. Nine of ten modified cycle periods for Operator A and three of ten modified cycle periods for Operator B had no points outside of the Normal control limits. The cycle times of these periods also exhibited no significant trends and could be considered to vary at random within Normal three sigma control limits. Concerning the total and modified cycle periods which had points outside of Normal or Type III control limits, it was notable that further analysis showed that every cycle time outside of the upper or lower limits contained one or more of the various internal delays discussed previously in Chapter IV.

Homogeneity of means and variances.—The findings of the tests for homogeneity of the variances of the half-day total and modified cycle distributions for Operators A and B showed that all of the four groups of ten distribution variances were significantly different from normal at the five percent level of confidence (see Table 5).

In Table 6 can be found the results of the analyses of variance of the means. The results showed that the variation between days and between morning and afternoon periods was significantly larger than the variation within half-day periods at the five percent confidence level.

Means of total and modified cycle times.—An analysis of the 95% confidence intervals for total and modified cycle distribution means for

Table 5. Significance of the Results of Bartlett's Test for Homogeneity of Variances of Distributions

Operator	Distribution	Pooled S^2	χ^2	f	Level of Significance
A	Total	.01445	309.17	9	.000001
A	Modified	.00441	42.45	9	.000001
B	Total	.01082	74.66	9	.000001
B	Modified	.00311	26.93	9	.005

Table 6. Significance of Sources of Variation of the Mean Values as Derived from Analysis of Variance

Source	SSD	f	M.S.	F Value	Level of Significance
			Operator A - Total Cycle Distributions		
Between Days	1.858	4	.4645	32.14	.0005
Between AM & PM (Within Days)	0.949	5	.1898	13.13	.0005
Within Days	30.121	2084	.0144		
Total	32.928	2093			
			Operator A - Modified Cycle Distributions		
Between Days	0.805	4	.2013	45.68	.0005
Between AM & PM (Within Days)	0.324	5	.0648	14.71	.0005
Within Days	7.789	1768	.0044		
Total	8.918	1777			
			Operator B - Total Cycle Distributions		
Between Days	1.574	4	.3935	36.39	.0005
Between AM & PM (Within Days)	0.419	5	.0838	7.75	.0005
Within Days	25.448	2353	.0108		
Total	27.441	2362			
			Operator B - Modified Cycle Distributions		
Between Days	1.149	4	.2873	92.28	.0005
Between AM & PM (Within Days)	0.164	5	.0328	10.537	.0005
Within Days	6.101	1960	.0031		
Total	7.414	1969			

Operators A and B, as illustrated in Tables 7-8, did not show a significant pattern of variation.

The results of an analysis of the deviation of half-day distribution means from the means of the grand distributions showed that six of ten, three of ten, three of ten, and two of ten of Operator A's total and modified cycle distributions and Operator B's total and modified cycle distributions respectively were not significantly different from their respective grand weekly means at the five percent confidence level. These significant levels are shown in Table 9.

The test of the morning mean against the afternoon mean of the same day showed a significant difference at the five percent confidence level in the majority of cases except that three of five morning and afternoon half-day total cycle distribution means were not significantly different. In thirty-five of forty tests, the means of full day distributions were significantly different from every other full day mean within the four groupings at the five percent confidence level. Tables of the significance of these differences may be found in Tables 10-11. In general, the means of all distributions varied significantly from period to period.

<u>Standard deviations of total and modified cycle times</u>.—Confidence intervals with 95% limits were derived for each half-day and weekly distribution standard deviations. The results of this did not indicate a pattern, and further tests were applied. These confidence intervals can be observed in Tables 12-13.

When the standard deviation of the morning distribution of each day was tested against the afternoon standard deviation of the same day,

Table 7. 95% Confidence Limits for Means of Half-Day and Weekly Distributions for Operator A

Distribution	Confidence Limits	N
	Total Cycle Distributions	
Mon.-AM	.9796 < 1.0094 < 1.0392	146
PM	.9054 < .9256 < .9458	130
Tue.-AM	.9048 < .9191 < .9334	228
PM	.8995 < .9126 < .9257	263
Wed.-AM	.8868 < .9003 < .9138	224
PM	.8444 < .8549 < .8653	270
Thu.-AM	.8801 < .8980 < .9153	218
PM	.8831 < .8953 < .9076	277
Fri.-AM	.9337 < .9545 < .9754	193
PM	.8854 < .9054 < .9253	147
Week	.9057 < .9112 < .9167	2094
	Modified Cycle Distributions	
Mon.-AM	.8231 < .8362 < .8494	125
PM	.7872 < .8004 < .8135	107
Tue.-AM	.7526 < .7613 < .7700	186
PM	.7674 < .7763 < .7852	223
Wed.-AM	.7662 < .7762 < .7861	202
PM	.7290 < .7367 < .7444	250
Thu.-AM	.7524 < .7624 < .7724	174
PM	.7553 < .7623 < .7693	226
Fri.-AM	.7924 < .8040 < .8156	150
PM	.7613 < .7727 < .7841	135
Week	.7704 < .7729 < .7754	1778

Table 8. 95% Confidence Limits for Means of Half-Day and Weekly Distributions for Operator B

Distribution	Confidence Limits	N
	Total Cycle Distributions	
Mon.-AM	.8872 < .8994 < .9116	220
PM	.9133 < .9312 < .9490	188
Tue.-AM	.8689 < .8814 < .8939	204
PM	.9033 < .9187 < .9342	241
Wed.-AM	.8482 < .8615 < .8747	250
PM	.8227 < .8356 < .8485	249
Thu.-AM	.8621 < .8747 < .8873	250
PM	.8465 < .8592 < .8719	221
Fri.-AM	.8501 < .8635 < .8768	252
PM	.8338 < .8439 < .8539	288
Week	.8703 < .8746 < .8790	2363
	Modified Cycle Distributions	
Mon.-AM	.7553 < .7628 < .7703	215
PM	.7669 < .7765 < .7861	157
Tue.-AM	.7563 < .7645 < .7727	182
PM	.7630 < .7716 < .7802	182
Wed.-AM	.7256 < .7334 < .7412	194
PM	.6972 < .7046 < .7118	169
Thu.-AM	.7439 < .7511 < .7583	218
PM	.7251 < .7331 < .7411	199
Fri.-AM	.7114 < .7195 < .7276	199
PM	.6962 < .7024 < .7086	255
Week	.7378 < .7405 < .7432	1970

Table 9. Significance of Deviation of Distribution Means from the Means of the Grand Distributions

Period	Mean	N	Z Value	Level of Significance	Mean	N	Z Value	Level of Significance
				Operator A				
	Total Cycle Distributions Grand Mean - 0.91122				Modified Cycle Distributions Grand Mean - 0.77287			
Mon.-AM	1.00938	146	6.462	.000001	0.83624	125	9.460	.000001
PM	0.92561	130	1.396	.20	0.80037	107	4.092	.0001
Tue.-AM	0.91908	228	1.076	.20	0.76129	186	2.607	.01
PM	0.91256	263	0.200	.20	0.77633	223	0.761	.20
Wed.-AM	0.90031	224	1.580	.20	0.77619	202	0.655	.20
PM	0.85485	270	10.565	.000001	0.73672	250	9.169	.000001
Thu.-AM	0.89796	216	1.502	.20	0.76236	174	2.061	.05
PM	0.89534	277	2.543	.02	0.76234	226	2.947	.01
Fri.-AM	0.95451	193	4.070	.0001	0.80400	150	5.277	.000001
PM	0.90537	147	0.575	.20	0.77274	135	0.022	.20
				Operator B				
	Total Cycle Distributions Grand Mean - 0.87464				Modified Cycle Distributions Grand Mean - 0.74048			
Mon.-AM	0.89941	220	3.969	.0001	0.76279	215	5.830	.000001
PM	0.93117	188	6.209	.000001	0.77649	157	7.363	.000001
Tue.-AM	0.88142	204	1.065	.20	0.76451	182	5.765	.000001
PM	0.91871	241	5.589	.000001	0.77159	182	7.087	.000001
Wed.-AM	0.86148	250	1.948	.05	0.73340	194	1.784	.10
PM	0.83558	249	5.938	.000001	0.70455	169	9.647	.000001
Thu.-AM	0.87472	250	0.012	.20	0.75110	218	2.884	.01
PM	0.85923	221	2.379	.02	0.73307	199	1.818	.10
Fri.-AM	0.86345	252	1.646	.10	0.71949	199	5.067	.000001
PM	0.84385	288	6.004	.000001	0.70239	255	12.055	.000001

Table 10. Significance of Differences Between Distribution Means - Operator A

Period	Mean	N	Z Value	Level of Significance	Mean	N	Z Value	Level of Significance
	Total Cycle Distributions				Modified Cycle Distributions			
Mon.-AM	1.00938	146	1.706	.10	0.83624	125	3.781	.001
vs PM	0.92561	130			0.80037	107		
Tue.-AM	0.91908	228	0.659	.20	0.76129	186	2.365	.02
vs PM	0.91256	263			0.77633	223		
Wed.-AM	0.90031	224	5.210	.000001	0.77619	202	6.146	.000001
vs PM	0.85485	270			0.73672	250		
Thu.-AM	0.89796	216	0.242	.20	0.76236	174	0.003	.20
vs PM	0.89534	277			0.76234	226		
Fri.-AM	0.95451	193	3.338	.001	0.80400	150	3.774	.001
vs PM	0.90537	147			0.77274	135		
Mon.-vs	0.96993	276	5.074	.000001	0.81970	232	8.381	.000001
Tue.	0.91373	491			0.76570	409		
Mon.-vs	0.96993	276	8.838	.000001	0.81970	232	11.065	.000001
Wed.	0.87547	494			0.75436	452		
Mon.-vs	0.96993	276	6.646	.000001	0.81970	232	9.964	.000001
Thu.	0.89649	493			0.76235	400		
Mon.-vs	0.96993	276	2.969	.01	0.81970	232	4.694	.00001
Fri.	0.93326	340			0.78919	285		
Tue.-vs	0.91373	491	5.570	.000001	0.76570	409	2.137	.02
Wed.	0.87547	494			0.75436	452		
Tue.-vs	0.91373	491	7.342	.000001	0.76570	409	0.652	.20
Thu.	0.89649	493			0.76235	400		
Tue.-vs	0.91373	491	2.112	.05	0.76570	409	3.940	.0001
Fri.	0.93326	340			0.78919	285		
Wed.-vs	0.87547	494	3.076	.01	0.75436	452	1.797	.10
Thu.	0.89649	493			0.76235	400		
Wed.-vs	0.87547	494	6.581	.000001	0.75436	452	6.479	.000001
Fri.	0.93326	340			0.78919	285		
Thu.-vs	0.89649	493	3.987	.0001	0.76235	400	5.510	.000001
Fri.	0.93326	340			0.78919	285		

Table 11. Significance of Differences Between Distribution Means - Operator B

Period	Mean	N	Z Value	Level of Significance	Mean	N	Z Value	Level of Significance
	Total Cycle Distributions				Modified Cycle Distributions			
Mon.-AM	0.89941	220	2.863	.01	0.76279	215	2.206	.05
vs PM	0.93117	188			0.77649	157		
Tue.-AM	0.88142	204	3.680	.001	0.76451	182	1.170	.20
vs PM	0.91871	241			0.77159	182		
Wed.-AM	0.86148	250	4.157	.0001	0.73340	194	5.300	.000001
vs PM	0.83558	249			0.70455	169		
Thu.-AM	0.87472	250	1.696	.10	0.75110	218	3.282	.002
vs PM	0.85923	221			0.73307	199		
Fri.-AM	0.86345	252	2.302	.05	0.71949	199	3.282	.002
vs PM	0.84385	288			0.70239	255		
Mon.-vs	0.91404	408	1.638	.20	0.76858	372	0.123	.20
Tue.	0.90162	445			0.76805	364		
Mon.-vs	0.91404	408	9.038	.000001	0.76858	372	11.654	.000001
Wed.	0.84856	499			0.71997	363		
Mon.-vs	0.91404	408	6.451	.000001	0.76858	372	6.602	.000001
Thu.	0.86745	471			0.74249	417		
Mon.-vs	0.91404	408	8.844	.000001	0.76858	372	14.709	.000001
Fri.	0.85300	540			0.70989	454		
Tue.-vs	0.90162	445	7.489	.000001	0.76805	364	11.552	.000001
Wed.	0.84856	499			0.71997	363		
Tue.-vs	0.90162	445	4.898	.00001	0.76805	364	6.484	.000001
Thu.	0.86745	471			0.74249	417		
Tue.-vs	0.90162	445	7.220	.000001	0.76805	364	14.613	.000001
Fri.	0.85300	540			0.70989	454		
Wed.-vs	0.84856	499	2.857	.01	0.71997	363	5.931	.000001
Thu.	0.86745	471			0.74249	417		
Wed.-vs	0.84856	499	0.699	.20	0.71997	363	2.627	.01
Fri.	0.85300	540			0.70989	454		
Thu.-vs	0.86745	471	2.292	.05	0.74249	417	9.063	.000001
Fri.	0.85300	540			0.70989	454		

Table 12. 95% Confidence Limits for Standard Deviations of Half-Day and Weekly Distributions for Operator A

Distribution	Confidence Limits	N
	Total Cycle Distributions	
Mon.-AM	.1625 < .1835 < .2046	146
PM	.1032 < .1175 < .1318	130
Tue.-AM	.1002 < .1103 < .1204	228
PM	.0991 < .1084 < .1176	263
Wed.-AM	.0938 < .1033 < .1129	224
PM	.0803 < .0877 < .0951	270
Thu.-AM	.1175 < .1297 < .1419	218
PM	.0953 < .1040 < .1126	277
Fri.-AM	.1330 < .1478 < .1625	193
PM	.1093 < .1234 < .1375	147
Week	.1241 < .1280 < .1319	2094
	Modified Cycle Distributions	
Mon.-AM	.0656 < .0749 < .0842	125
PM	.0602 < .0695 < .0788	107
Tue.-AM	.0544 < .0606 < .0668	186
PM	.0616 < .0679 < .0743	223
Wed.-AM	.0650 < .0720 < .0791	202
PM	.0569 < .0623 < .0678	250
Thu.-AM	.0602 < .0673 < .0743	174
PM	.0488 < .0537 < .0587	226
Fri.-AM	.0641 < .0723 < .0804	150
PM	.0595 < .0676 < .0756	135
Week	.0729 < .0754 < .0779	1778

Table 13. 95% Confidence Limits for Standard Deviations of Half-Day and Weekly Distributions for Operator B

Distribution	Confidence Limits	N
	Total Cycle Distributions	
Mon.-AM	.0839 < .0926 < .1012	220
PM	.1122 < .1248 < .1375	188
Tue.-AM	.0821 < .0909 < .0998	204
PM	.1115 < .1224 < .1333	241
Wed.-AM	.0974 < .1068 < .1162	250
PM	.0947 < .1038 < .1129	249
Thu.-AM	.0929 < .1018 < .1108	250
PM	.0873 < .0963 < .1053	221
Fri.-AM	.0985 < .1079 < .1173	252
PM	.0799 < .0870 < .0941	288
Week	.1052 < .1083 < .1114	2363
	Modified Cycle Distributions	
Mon.-AM	.0508 < .0561 < .0614	215
PM	.0545 < .0613 < .0681	157
Tue.-AM	.0505 < .0562 < .0620	182
PM	.0531 < .0592 < .0653	182
Wed.-AM	.0498 < .0553 < .0608	194
PM	.0433 < .0484 < .0536	169
Thu.-AM	.0493 < .0544 < .0595	218
PM	.0519 < .0575 < .0632	199
Fri.-AM	.0527 < .0584 < .0642	199
PM	.0460 < .0505 < .0548	255
Week	.0595 < .0614 < .0633	1970

the results showed that the morning variation was significantly different at the five percent confidence level from the afternoon variation in eleven of the twenty cases tested.

When the standard deviation of each full day distribution of Operator A was tested against each other full day distribution standard deviation, nine of ten and seven of ten tests of the total and modified cycle distribution standard deviations respectively showed a significant difference at the five percent confidence level. On the other hand, when Operator B's full day distribution standard deviations were tested against one another, only five of ten and two of ten tests of the total and modified cycle distribution standard deviations respectively showed a significant difference.

The experienced Operator, B, showed definite indications of a constant variation from day to day. Tables of the significance of the differences between standard deviations can be found in Tables 14-15.

<u>Measures of Skewness and Peakedness</u>.--Some of the results of testing the skewness and peakedness of the half-day distributions for normality were surprising in light of the results of previous research at Georgia Tech. All values of the total cycle time distribution measures of skewness and peakedness were significantly different from normal at the five percent confidence level for both Operators A and B. These results substantiate the results of previous research for short cycle manual repetitive operations.

But, for the modified cycle time distributions, two of ten and four of ten values for skewness for Operators A and B respectively were not significantly different from normal at the five percent level of

Table 14. Significance of Differences Between Distribution Standard Deviations for Operator A

Period	Std.Dev.	f	F Value	Level of Significance	S.D.	f	F Value	Level of Significance
	Total Cycle Distributions				Modified Cycle Distributions			
Mon.-AM	.18354	145	2.438	.0005	.07489	124	1.161	.20
vs PM	.11753	129			.06951	106		
Tue.-AM	.11028	227	1.036	.20	.06059	185	1.257	.10
vs PM	.10838	262			.06794	222		
Wed.-AM	.10334	223	1.389	.01	.07204	201	1.336	.025
vs PM	.08767	269			.06234	249		
Thu.-AM	.12971	215	1.557	.001	.06727	173	1.570	.005
vs PM	.10395	276			.05371	225		
Fri.-AM	.14775	192	1.433	.01	.07225	149	1.140	.20
vs PM	.12340	146			.06755	134		
Mon.-vs	.16186	275	1.916	.0005	.07476	231	1.273	.025
Tue.	.11705	490			.08438	408		
Mon.-vs	.16186	275	2.733	.0005	.07476	231	1.150	.20
Wed.	.09788	493			.06971	451		
Mon.-vs	.16186	275	1.942	.0005	.07476	231	1.550	.0005
Thu.	.11619	492			.06008	399		
Mon.-vs	.16186	275	1.333	.025	.07476	231	1.082	.20
Fri.	.14036	339			.07190	284		
Tue.-vs	.11705	490	1.426	.0005	.08438	408	1.463	.0005
Wed.	.09788	493			.06971	451		
Tue.-vs	.11705	490	1.014	.20	.08438	408	1.973	.0005
Thu.	.11619	492			.06008	399		
Tue.-vs	.11705	490	1.437	.0005	.08438	408	1.377	.01
Fri.	.14036	339			.07190	284		
Wed.-vs	.09788	493	1.407	.0005	.06971	451	1.348	.005
Thu.	.11619	492			.06008	399		
Wed.-vs	.09788	493	2.050	.0005	.06971	451	1.063	.20
Fri.	.14036	339			.07190	284		
Thu.-vs	.11619	492	1.457	.0005	.06008	399	1.433	.005
Fri.	.14036	339			.07190	284		

Table 15. Significance of Differences Between Distributions Standard Deviations for Operator B

Period	Std.Dev.	f	F Value	Level of Significance	S.D.	f	F Value	Level of Significance
	Total Cycle Distributions				Modified Cycle Distributions			
Mon.-AM	.09256	219	1.847	.0005	.05611	214	1.193	.20
vs PM	.12484	187			.06128	156		
Tue.-AM	.09091	203	1.813	.0005	.05623	181	1.109	.20
vs PM	.12241	240			.05922	181		
Wed.-AM	.10680	249	1.059	.20	.05529	193	1.304	.05
vs PM	.10381	248			.04842	168		
Thu.-AM	.10183	249	1.118	.20	.05437	217	1.119	.20
vs PM	.09629	220			.05750	198		
Fri.-AM	.10792	251	1.538	.0005	.05844	198	1.341	.025
vs PM	.08703	287			.05046	254		
Mon.-vs	.11045	407	1.007	.20	.05882	371	1.031	.20
Tue.	.11091	444			.05796	363		
Mon.-vs	.11045	407	1.080	.20	.05882	371	1.177	.10
Wed.	.10630	498			.06277	362		
Mon.-vs	.11045	407	1.227	.05	.05882	371	1.313	.01
Thu.	.09970	470			.06033	416		
Mon.-vs	.11045	407	1.272	.025	.05882	371	1.151	.20
Fri.	.09793	539			.05486	453		
Tue.-vs	.11091	444	1.088	.20	.05796	363	1.141	.20
Wed.	.10630	498			.06277	362		
Tue.-vs	.11091	444	1.236	.025	.05796	363	1.273	.025
Thu.	.09970	470			.06033	416		
Tue.-vs	.11091	444	1.280	.025	.05796	363	1.117	.20
Fri.	.09793	539			.05486	453		
Wed.-vs	.10630	498	1.136	.10	.06277	362	1.116	.20
Thu.	.09970	470			.06033	416		
Wed.-vs	.10630	498	1.177	.05	.06277	362	1.022	.20
Fri.	.09793	539			.05486	453		
Thu.-vs	.09970	470	1.036	.20	.06033	416	1.140	.20
Fri.	.09793	539			.05486	453		

significance. And further, for the modified cycle time distributions, seven of ten and ten of ten values for peakedness for Operators A and B respectively were not significantly different from normal at the five percent level of significance. These test results may be found in Tables 16-17. The results infer that the continued identification and removal of assignable causes of variation will result in normal rather than skewed individual distributions for operations of the type studied.

Table 16. Significance of Differences from the Normal Distribution for Distribution Measures of Skewness g_1 and Peakedness g_2 for Operator A

Period	N	g_1	Level of Significance	g_2	Level of Significance
		Total Cycle Distributions			
Mon.-AM	146	1.788	All	7.062	< .01
PM	130	2.058	values	10.597	< .01
Tue.-AM	228	1.457	are	7.363	< .01
PM	263	0.793	less	3.606	.05
Wed.-AM	224	0.723	than	4.199	< .01
PM	270	0.669	.01	4.196	< .01
Thu.-AM	216	1.880		10.570	< .01
PM	277	1.154		5.789	< .01
Fri.-AM	193	1.227		6.799	< .01
PM	147	1.764		7.915	< .01
		Modified Cycle Distributions			
Mon.-AM	125	0.229	> .05	2.556	> .05
PM	107	0.473	.05	2.703	> .05
Tue.-AM	186	0.233	> .05	2.552	.05
PM	223	0.275	.05	2.652	.05
Wed.-AM	202	0.395	.01	2.981	> .05
PM	250	0.718	< .01	3.740	.05
Thu.-AM	174	0.508	< .01	2.979	> .05
PM	226	0.355	.05	3.219	> .05
Fri.-AM	150	0.294	.05	2.650	> .05
PM	135	0.525	< .01	2.785	> .05

Table 17. Significance of Differences from the Normal Distribution for Distribution Measures of Skewness g_1 and Peakedness g_2 for Operator B

Period	N	g_1	Level of Significance	g_2	Level of Significance
			Total Cycle Distributions		
Mon.–AM	220	1.269	All	5.725	All
PM	188	1.768	values	10.097	values
Tue.–AM	204	0.935	are	4.681	are
PM	241	2.479	less	15.408	less
Wed.–AM	250	1.982	than	9.759	than
PM	249	0.853	.01	5.684	.01
Thu.–AM	250	1.383		6.283	
PM	221	1.286		7.211	
Fri.–AM	252	1.650		9.752	
PM	288	1.553		7.690	
			Modified Cycle Distributions		
Mon.–AM	215	0.287	.05	3.208	All
PM	157	0.280	$> .05$	2.524	values
Tue.–AM	182	0.159	$> .05$	2.970	are
PM	182	0.074	$> .05$	3.041	greater
Wed.–AM	194	0.343	.05	2.794	than
PM	169	0.652	$< .01$	3.404	.05
Thu.–AM	218	0.207	$> .05$	2.974	
PM	199	0.582	$< .01$	3.249	
Fri.–AM	199	0.361	.05	3.021	
PM	255	0.321	.05	2.942	

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

General Nature of Results of Study.--At this point it becomes desirable to review the general nature of this investigation. The principal purpose of this study was to investigate a worker's performance over a long period of time to determine if the cycle times of the worker exhibited any statistically predictable pattern. The operation studied was a long cycle, manual, repetitive, worker-controlled, non-assembly type operation. A secondary purpose was to compare the results of this investigation with the results of previous research in work measurement at the Georgia Institute of Technology.

The results indicated that there was generally no pattern to the variation of an operator's cycle times. The results of the previous work at Georgia Tech were also partially substantiated by this investigation.

From an analysis of linear trend, control charts, and the test based on the mean square successive differences, the results indicated that the modified cycle time distributions were predominantly in a state of statistical control and they also partially exhibited a pattern of random variation. A study of the data substantiated the results of previous research at Georgia Tech in that the results of this study indicate a direct relationship between the mean and standard deviation for a long cycle, manual, repetitive, worker-controlled, non-assembly type operation. However, the distribution measures of skewness and peakedness for this study were in contrast with the results of previous work in that the statistics for the modified cycle time distributions were not significantly different from normal in most cases. This infers that a longer cycle operation may actually have a theoretical normal distribution. The inference is not clear when the modified cycle time distributions are evaluated by themselves. But, when the modified cycle time distributions are compared with the total cycle time distributions, the trend toward normality becomes more evident.

This trend toward normality might be due to the fact that the cycle length for a long cycle time operation is not as strictly bound by a physiological lower limit as is the case with a short cycle time operation. Another cause of this trend toward normality could be due to the fact that many causes of variation in both short cycle and long cycle operations are similar or identical as to type and duration of time consumed by the departure from the established motion pattern. These delays might cause a significant skewness to be present in the short cycle time distribution whereas the same type of delay might have little or no effect on the skewness of a long cycle operation.

Specific Conclusions.--The conclusions for this study are all based on an investigation of two operators performing a long cycle, manual, repetitive, worker-controlled, non-assembly type operation in an industrial setting in the Atlanta, Georgia area.

The specific conclusions in light of the objectives are:

1. There was no significant linear trend to the work-time series for half-day, daily, or full weekly periods, with or without

the time consumed by assignable causes of variation intact in the work-times.

2. The distributions in about half of the cases tested exhibited a pattern of random variation.

3. None of the total cycle time distributions were in a normal state of statistical control but nearly all of the modified cycle time distributions were in a state of normal statistical control.

4. The distribution measures of skewness and peakedness for the total cycle time distributions were significantly different from normal, but the statistics for the modified cycle time distributions, in over half of the cases, showed no significant difference from normality.

5. The mean values for each period were significantly different from the mean values for other periods in most cases tested, although there was homogeneity between morning and afternoon means in some cases.

6. There was no significant difference between the standard deviations of different periods in the majority of cases tested for Operator B. Operator A's standard deviations varied considerably.

Additional conclusions are:

7. The coefficients of variation for the half-day and daily total and modified cycle time distributions were nearly constant, having a very small variation.

8. The standard deviations of the distributions varied directly with the mean values.

9. Removal of assignable causes of variation from an operation of this type may result in the cycle times being normally distributed.

10. The use of higher polynomials rather than the use of linear trend might show a pattern for a time series of a worker's cycle times.

Limitations.—All of the results, inferences, and conclusions of this study must be viewed in the light of the following limitations to the study:

1. The study was conducted as an investigation in an industrial setting and was not a controlled laboratory experiment.
2. Selection of the operators was not random.
3. The supply of shirts was not constant.
4. The shirts varied considerably as to type, size, weight, texture of the cloth, and degree of dampness.
5. There were many variations from the standard method.
6. Only two operators were observed.
7. Only one operation was studied.
8. The observation period was only one week for each operator.
9. Other uncontrollable variables which limited the findings of this investigation are mentioned in Chapter IV.

Recommendations for Future Studies.—The results of this investigation and of other previous and concurrent research in work measurement have a definite exploratory value but the limitations of this and the other studies seriously restrict the results of the work. The conditions that are inherent in an industrial situation are the principal reasons for the presence of the many limitations of previous studies. The observers had little or no control over any of the factors affecting the operation studied.

It now seems that it might be time to return to controlled research experiments in work measurement in order to eliminate or control many of the variables inseparable from any industrial situation.

Nevertheless, this study, performed in an industrial setting, has shown that the concept of normality as applied to work-time frequency distributions may have some validity. Further research should be conducted either in a laboratory or in an industrial setting to further substantiate or refute the results of this investigation.

Continued use should be made of the Rich Electronic Computer Center at Georgia Tech in order to facilitate rapid processing of data and to build up a permanent library of statistical routines.

With persistent basic and applied research into work measurement, it can be expected that better techniques and valid concepts will result to help solve practical problems in this area.

APPENDIX A

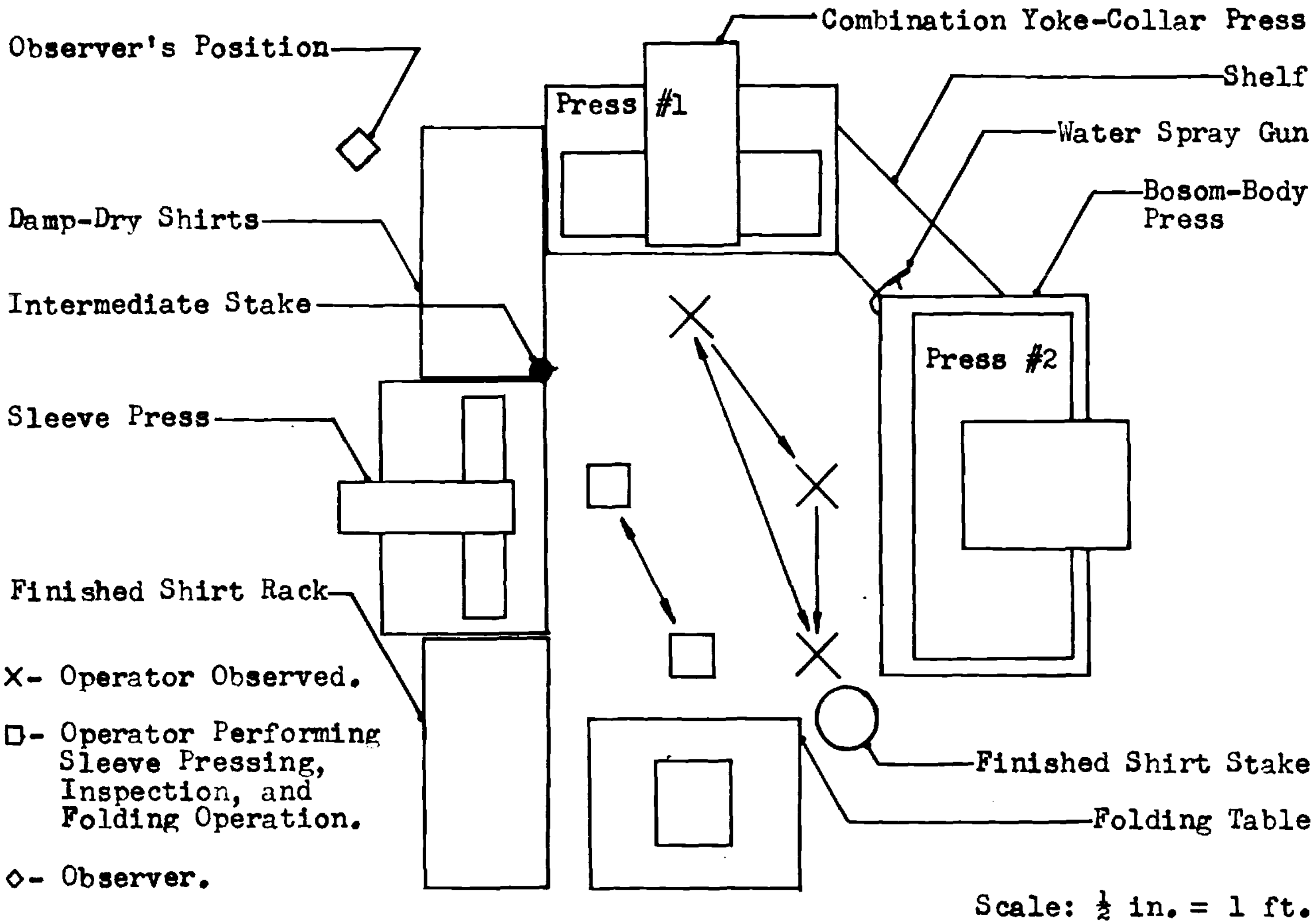


Fig. 4 . Workplace Layout for Observed Operation

1. Pick shirt with sleeves pressed off intermediate stake with left hand, right hand idle.

2. Open press No. 1 with right hand.

3. Pull out shirt with both hands and aside shirt with right hand to shelf between presses Nos. 1 and 2.

4. Position and place shirt in left hand so as to press collar in center press of press No. 1, smooth out collar with both hands.

5. Grasp left cuff, position and place with both hands on left cuff press of press No. 1.

6. Move over to right, grasp right cuff, position and place with both hands on right cuff press of press No. 1.

7. Move to center and smooth out collar.

8. Press buttons with both hands to close press No. 1.

9. Move to press No. 2, depress right button with right hand to open press No. 2.

10. Remove shirt from press after releasing collar stay with left hand and holding bar with left hand, reverse shirt, position and place on right side of press No. 2 to press one-half of back, smooth out.

11. Close press No. 2 with both hands.

12. Wait, open press No. 2 with right hand.

13. Move shirt in press over to press second-half of back, smooth out.

14. Close press No. 2.

15. Move to left and grasp shirt from between presses Nos. 1 and 2 with left hand, wait.

16. Open press No. 2 with right hand.

17. Aside finished shirt from right side of press No. 2 to finished stake with right hand.

18. Move to left, position and place shirt in left hand on left side of press No. 2 to press front of shirt, fix collar with both hands and place collar stay with left hand, smooth out front with both hands and place bar to hold shirt, smooth out again and wet (if necessary).

Fig. 2. Standard Method for Shirt Pressing Operation.

(continued)

19. Close press No. 2 with both hands.

20. Move to finished stake and button the top button on shirt (skip this step if shirt is already buttoned), move to press No. 1.

21. Open press No. 1 with both hands.

22. Grasp shirt in press with both hands, remove, position and place to press yoke (upper back section of shirt), smooth out.

23. Close press No. 1 with both hands.

24. Reach for shirt on intermediate stake.

Method followed by Operator A:

Operator A followed the standard method only about five percent of the time. This operator did not introduce any new motions, but changed the sequence of performance. Operator A's sequence of the steps was as follows: 1, 2, 3, 4, 5, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 9, 10, 11, 24. Approximately fifteen percent of the observed cycles of the operation contained variations in method, unusual shirts, or both.

Method followed by Operator B:

Operator B followed the standard method approximately fifty percent of the time. During the remainder of the time, this operator would button the finished shirt (step twenty) between steps ten and eleven. Approximately sixteen percent of the observed cycles of the operation contained variations in method, unusual shirts, or both.

Fig. 2. Standard Method for Shirt Pressing Operation.

Table 18. Hours Worked and Number of Cycles Observed Per Day

Day of Week	Date Nov., 1956	Hours of Work	Total Working Time	No. Raw Cycles	No. Mod. Cycles
		Operator A			
Tue.	6	8:18A.M.-5:15P.M.	7 hrs. 39 min.	491	409
Wed.	7	8:17A.M.-5:04P.M.	7 hrs. 26 min.	494	452
Thur.	8	8:16A.M.-5:15P.M.	7 hrs. 41 min.	493	400
Fri.	9	8:02A.M.-3:30P.M.	5 hrs. 37 min.	340	285
Mon.	12	8:03A.M.-3:14P.M.	4 hrs. 33 min.	276	232
		Totals:	32 hrs. 56 min.	2094	1778
		Operator B			
Thur.	15	8:05A.M.-4:08P.M.	6 hrs. 26 min.	471	417
Fri.	16	8:16A.M.-5:02P.M.	7 hrs. 54 min.	540	454
Mon.	19	8:08A.M.-3:45P.M.	6 hrs. 13 min.	408	372
Tue.	20	8:17A.M.-5:00P.M.	6 hrs. 50 min.	445	364
Wed.	21	8:06A.M.-4:51P.M.	7 hrs. 19 min.	499	363
		Totals:	34 hrs. 42 min.	2363	1970

APPENDIX B

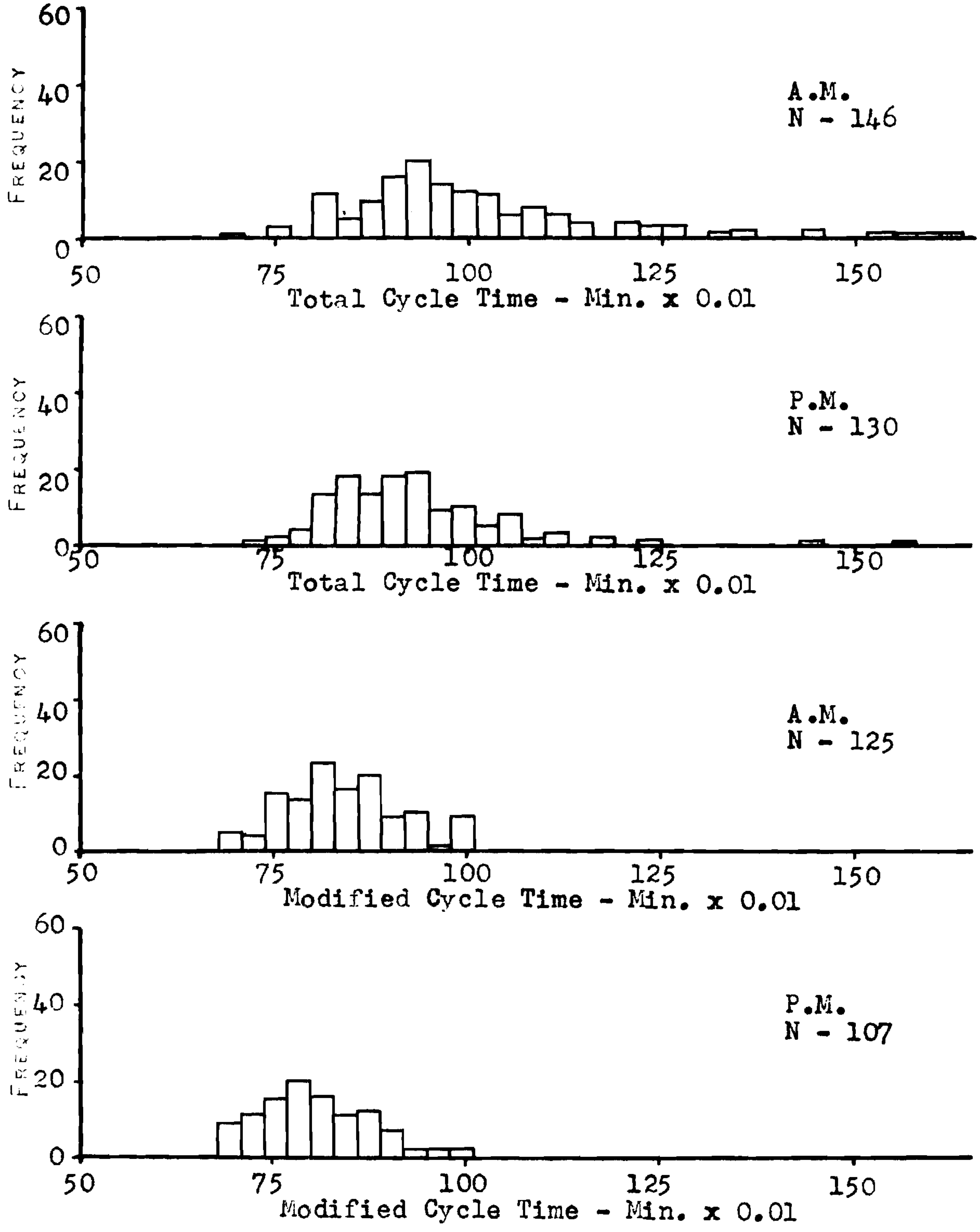


Fig. 3. Frequency Histograms - Operator A - Monday

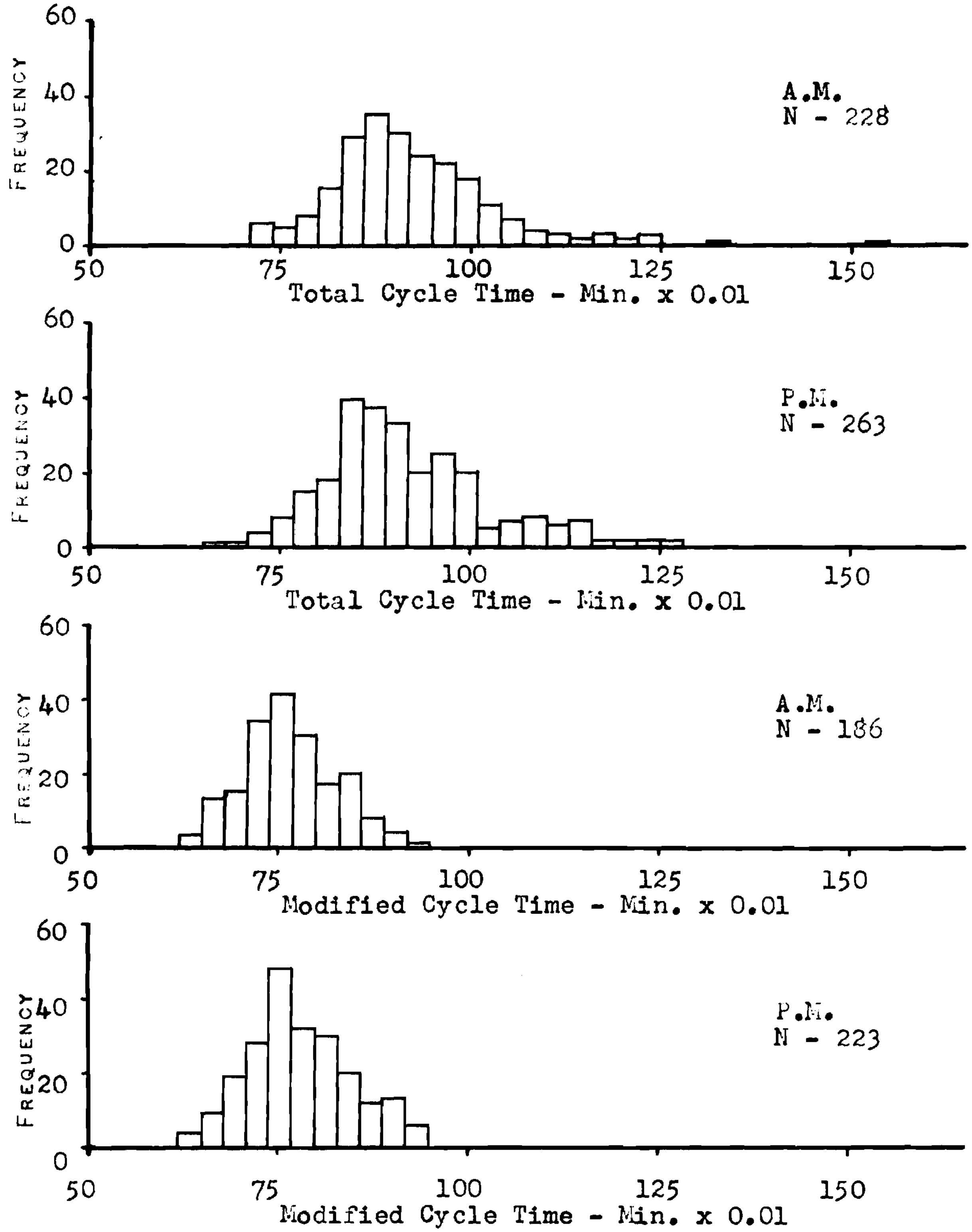


Fig. 4 . Frequency Histograms - Operator A - Tuesday

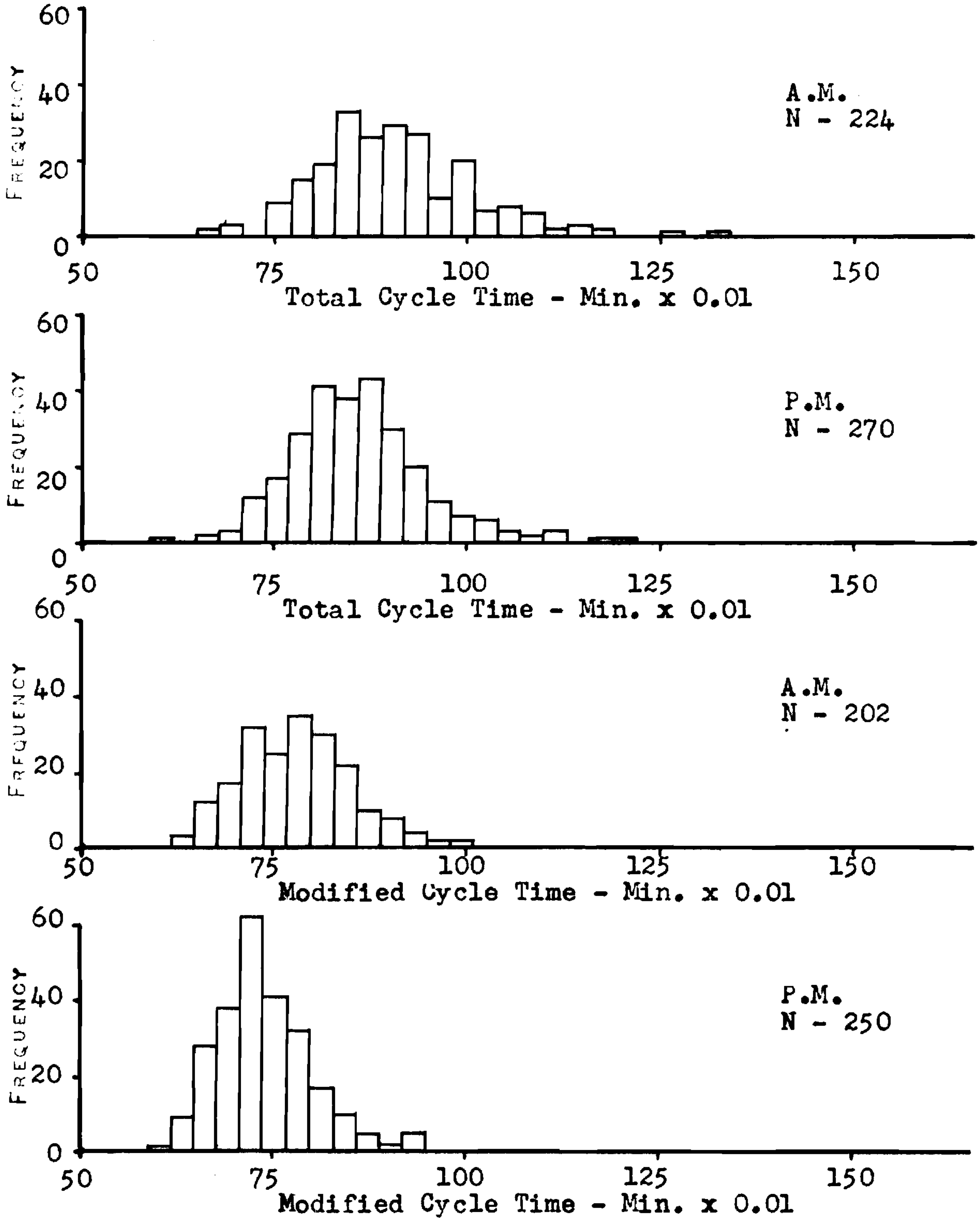


Fig. 5. Frequency Histograms - Operator A - Wednesday

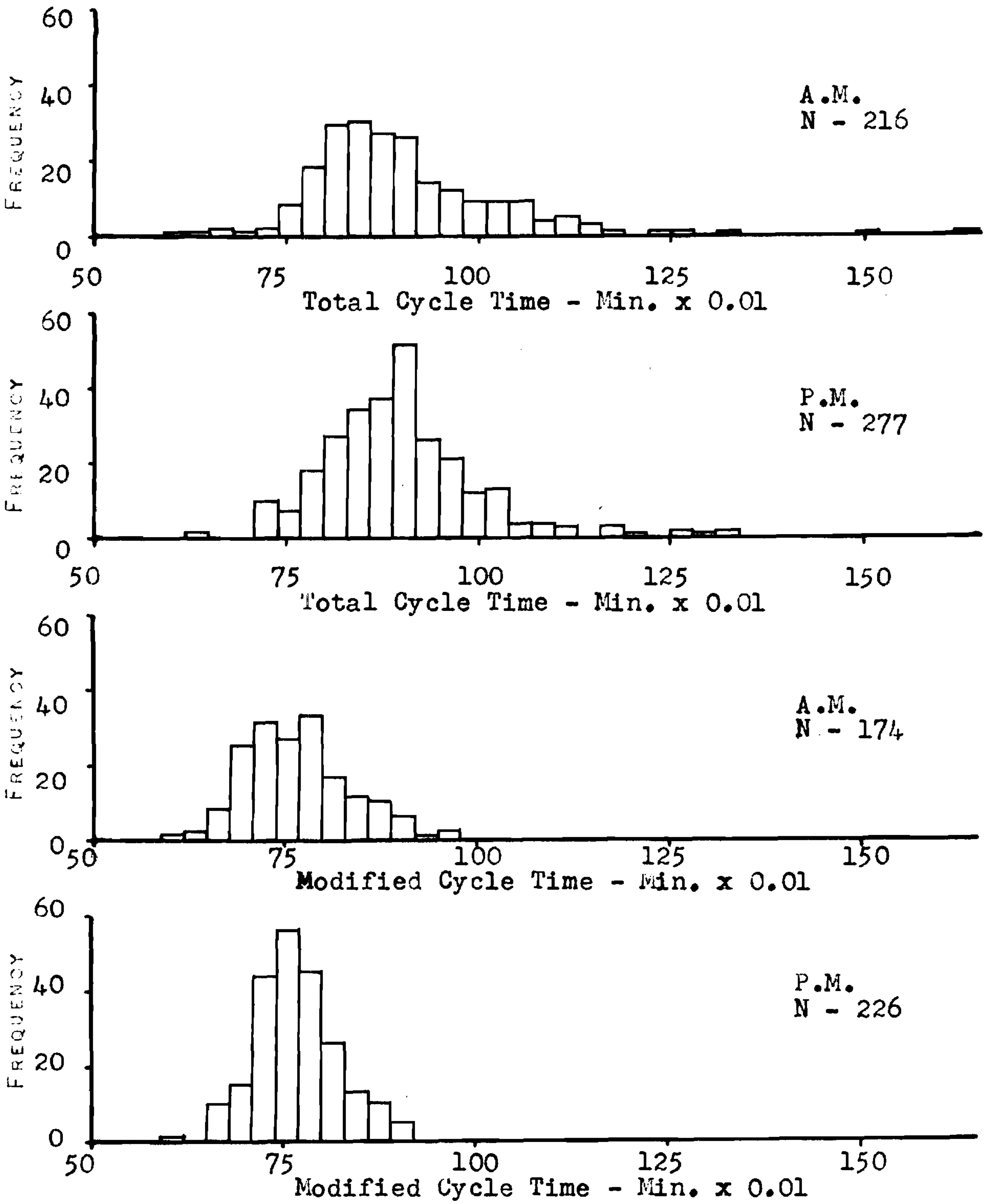


Fig. 6. Frequency Histograms - Operator A - Thursday

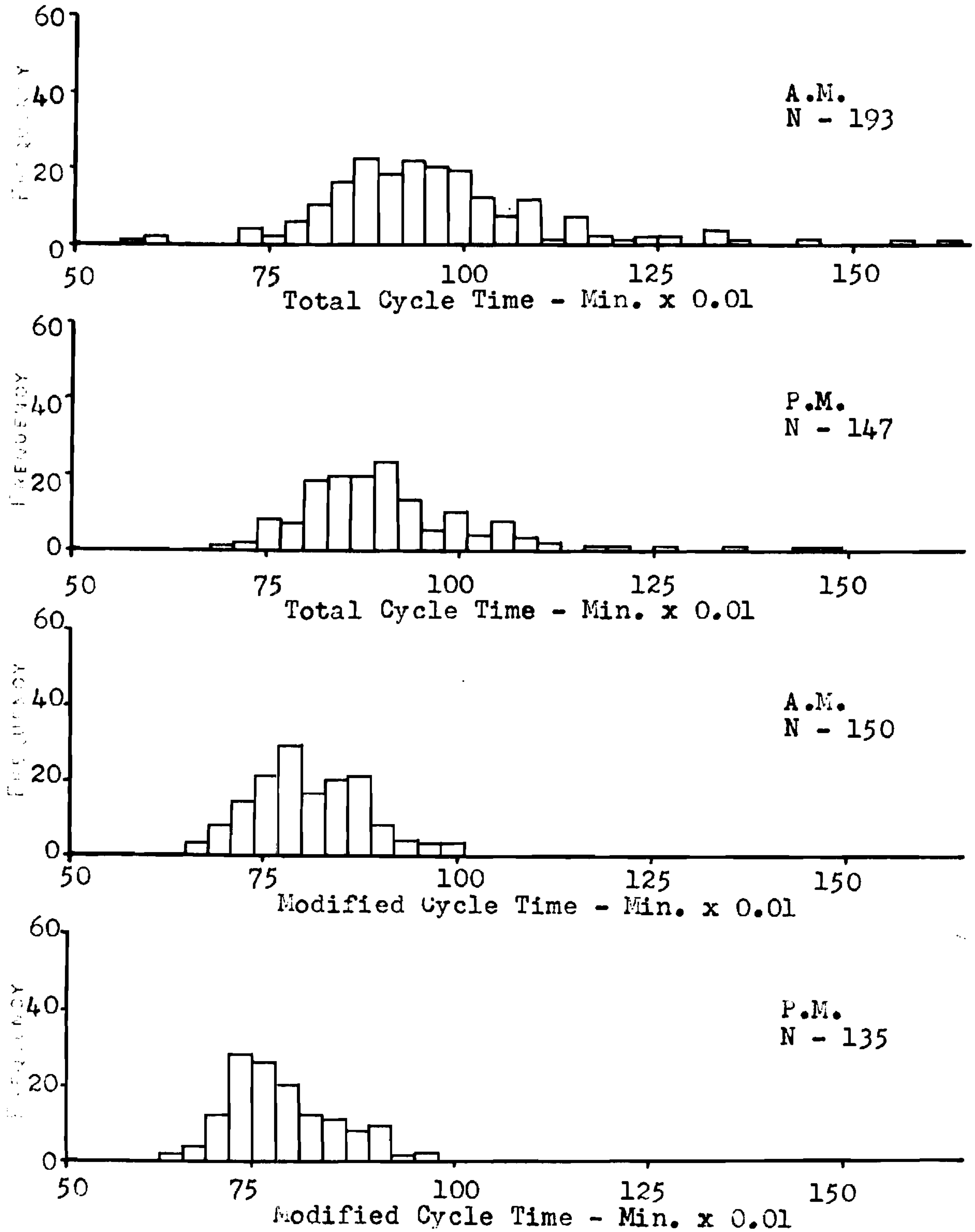
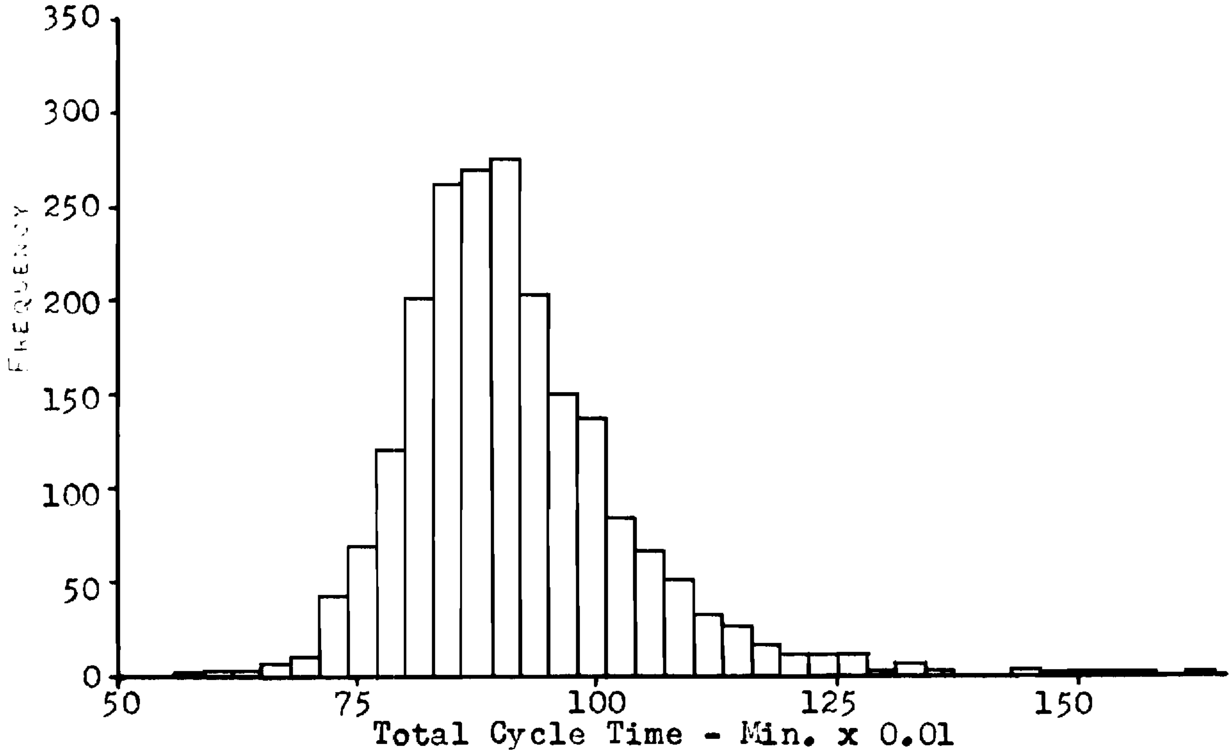


Fig. 7. Frequency Histograms - Operator A - Friday



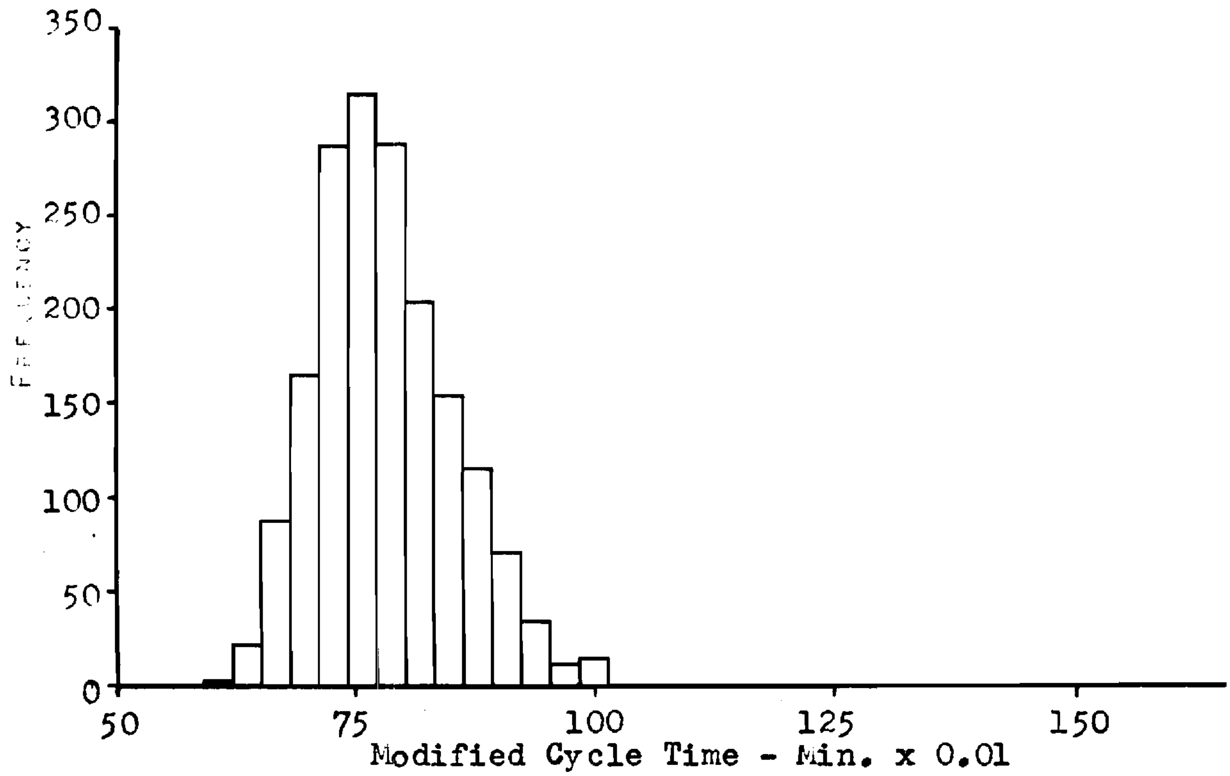


Fig. 8. Grand Frequency Histograms - Operator A

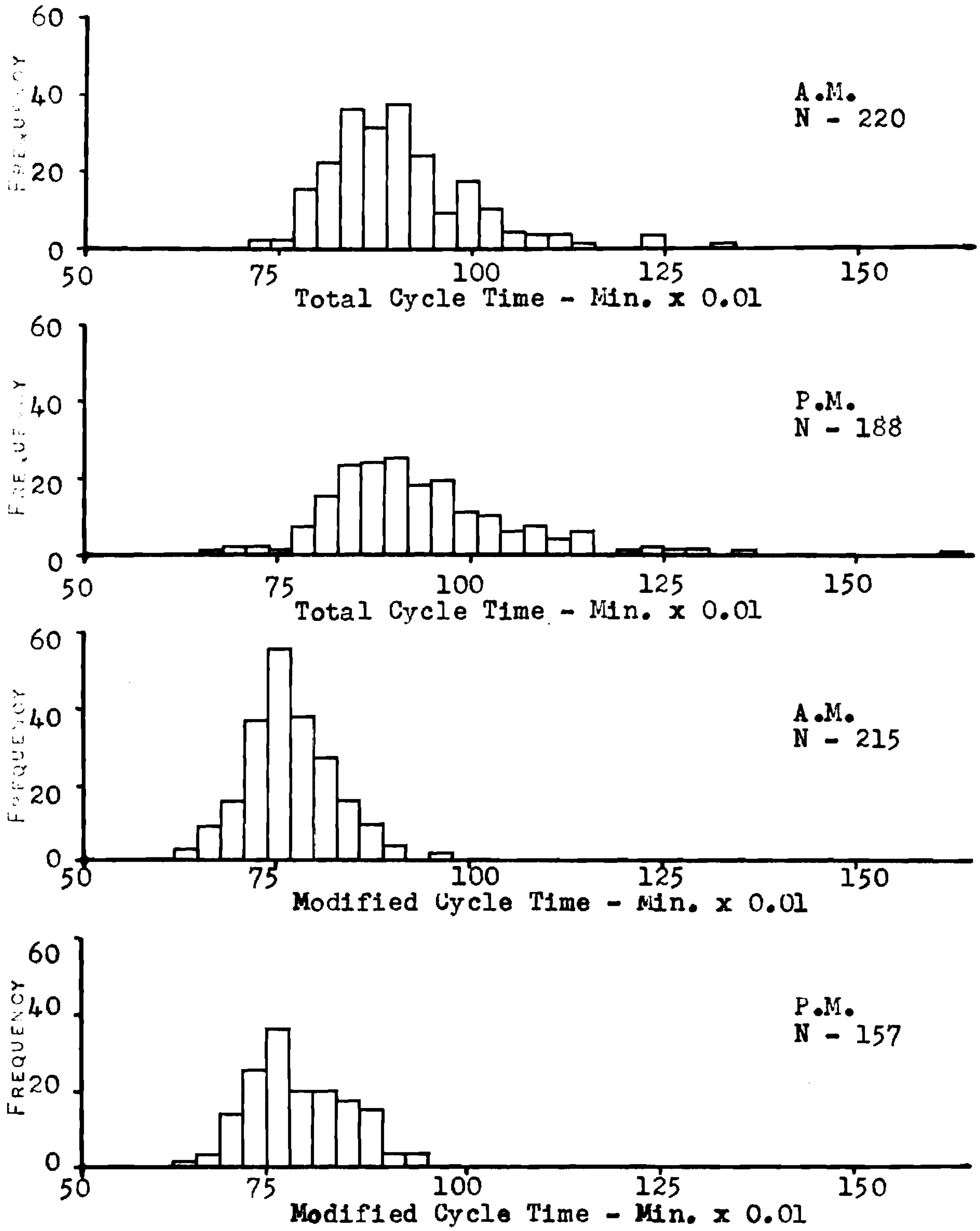


Fig. 9. Frequency Histograms - Operator B - Monday

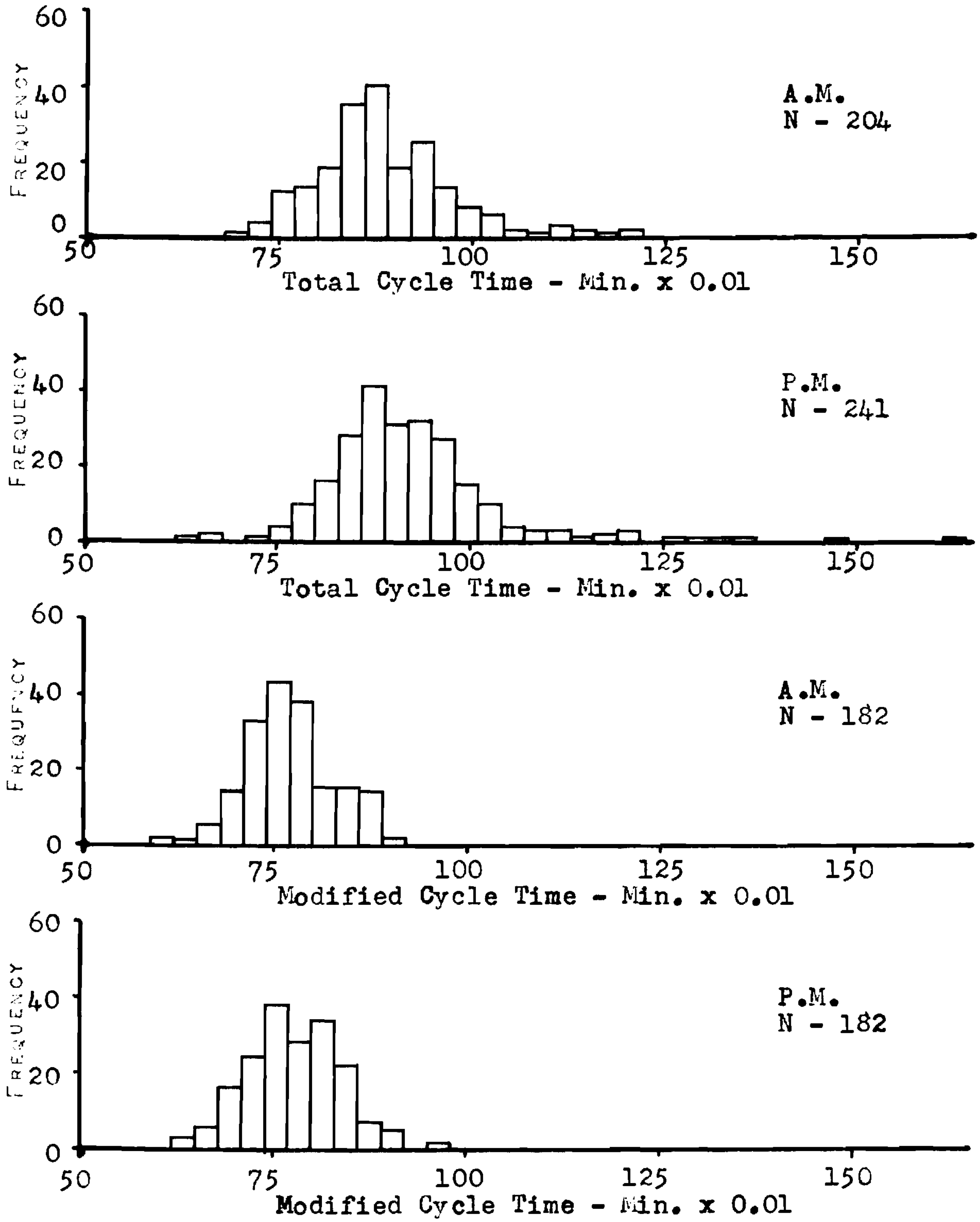


Fig. 10. Frequency Histograms - Operator B - Tuesday

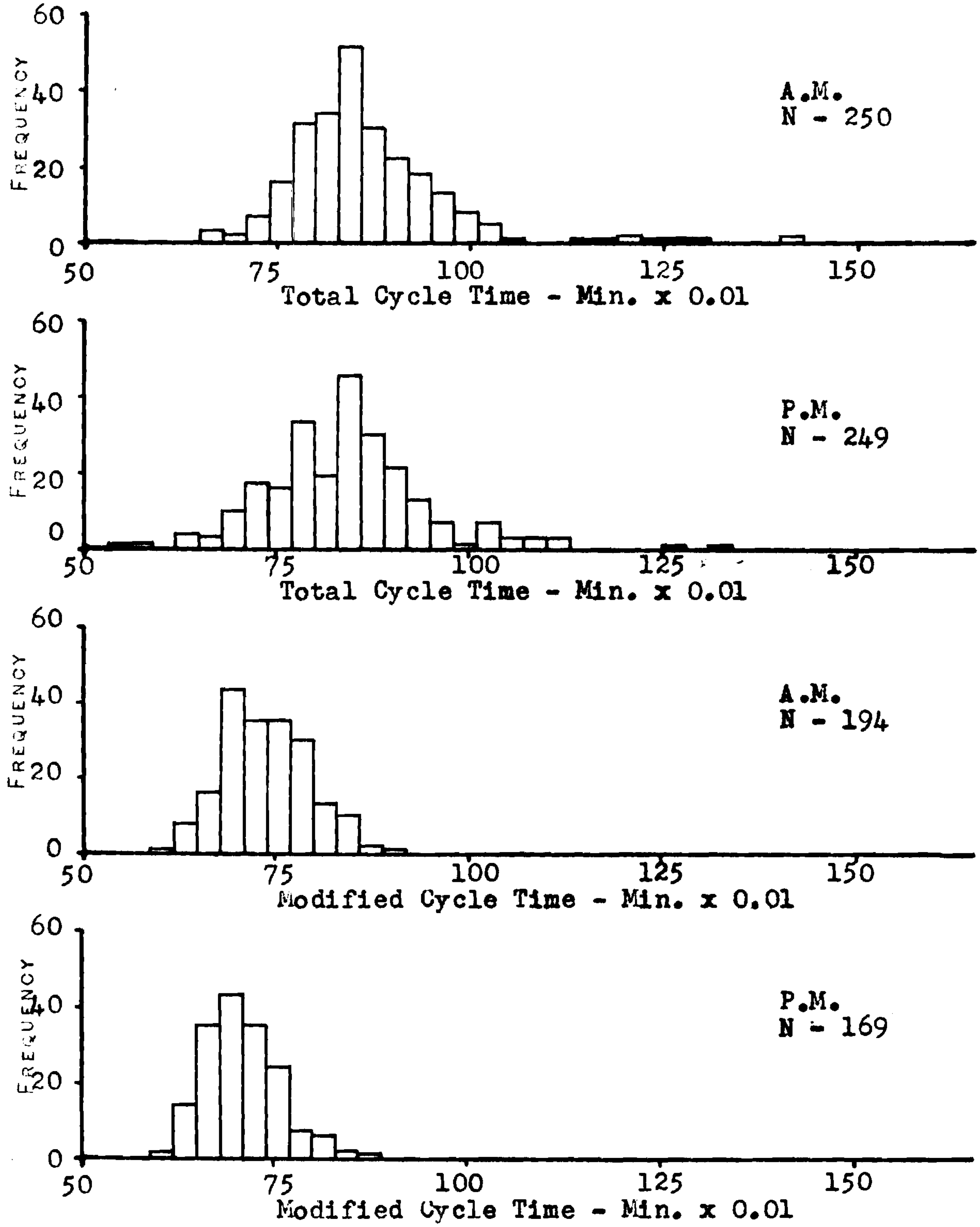


Fig. 11. Frequency Histograms - Operator B - Wednesday

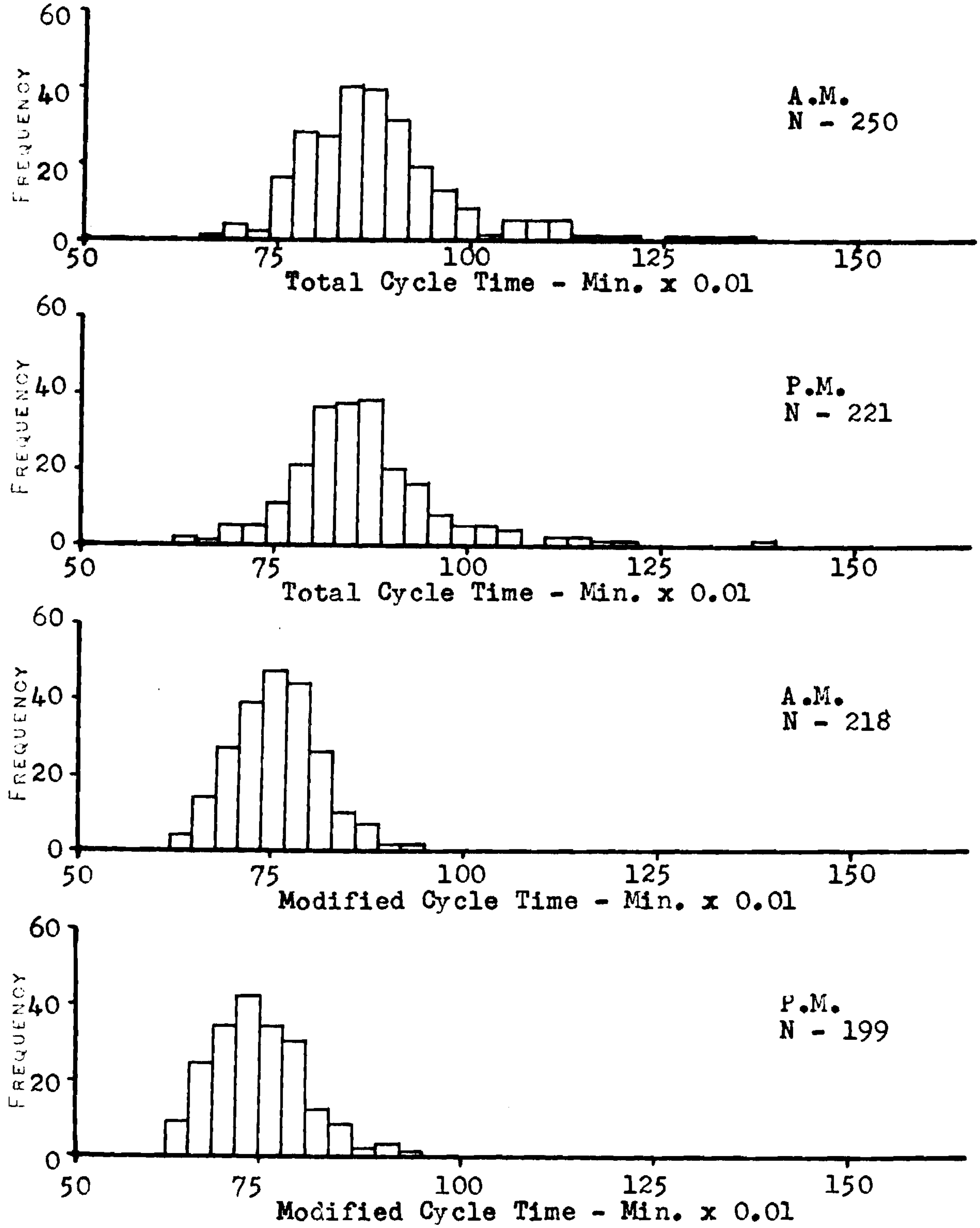


Fig. 12. Frequency Histograms - Operator B - Thursday

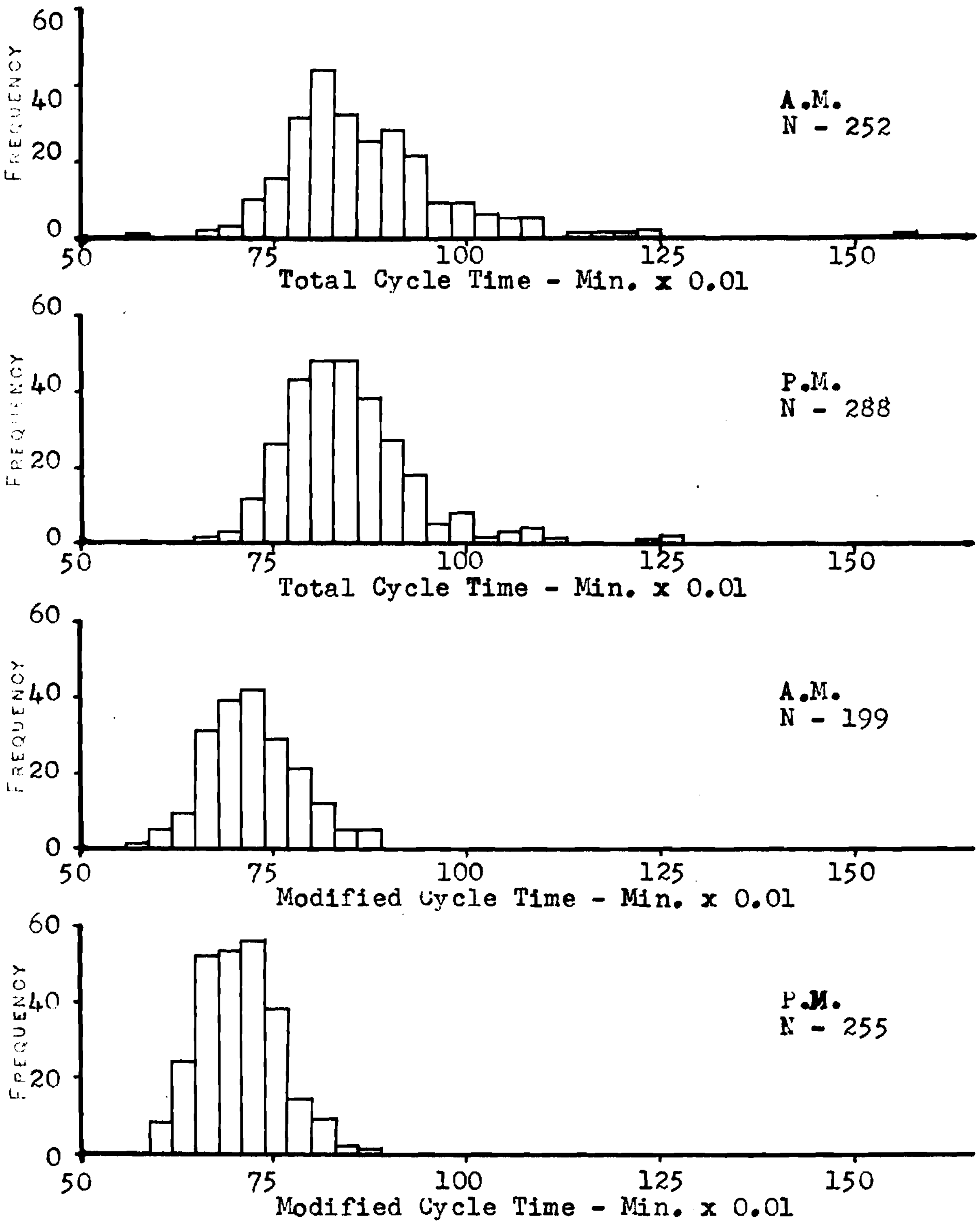


Fig. 13. Frequency Histograms - Operator B - Friday

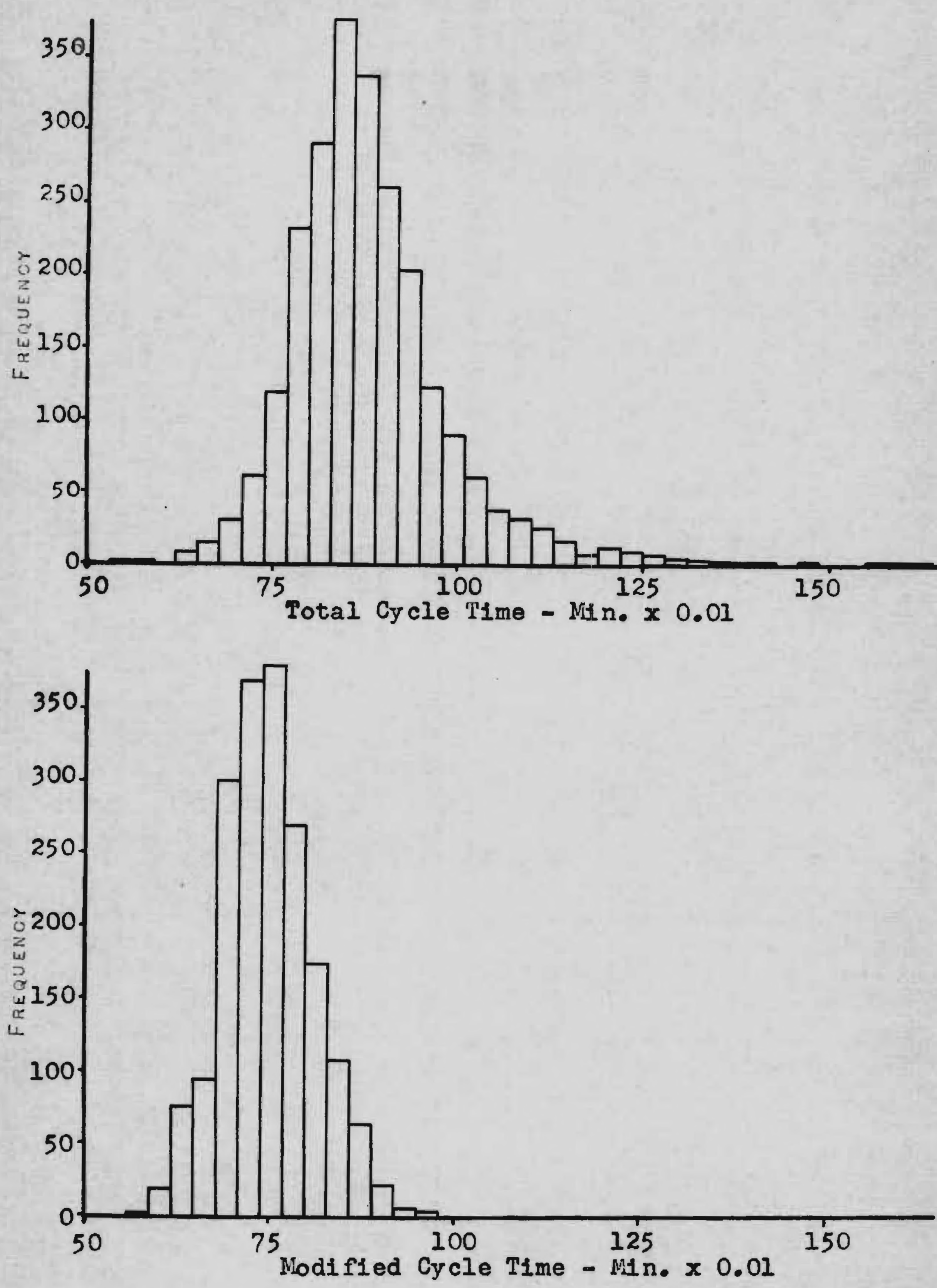


Fig. 14. Grand Frequency Histograms - Operator B

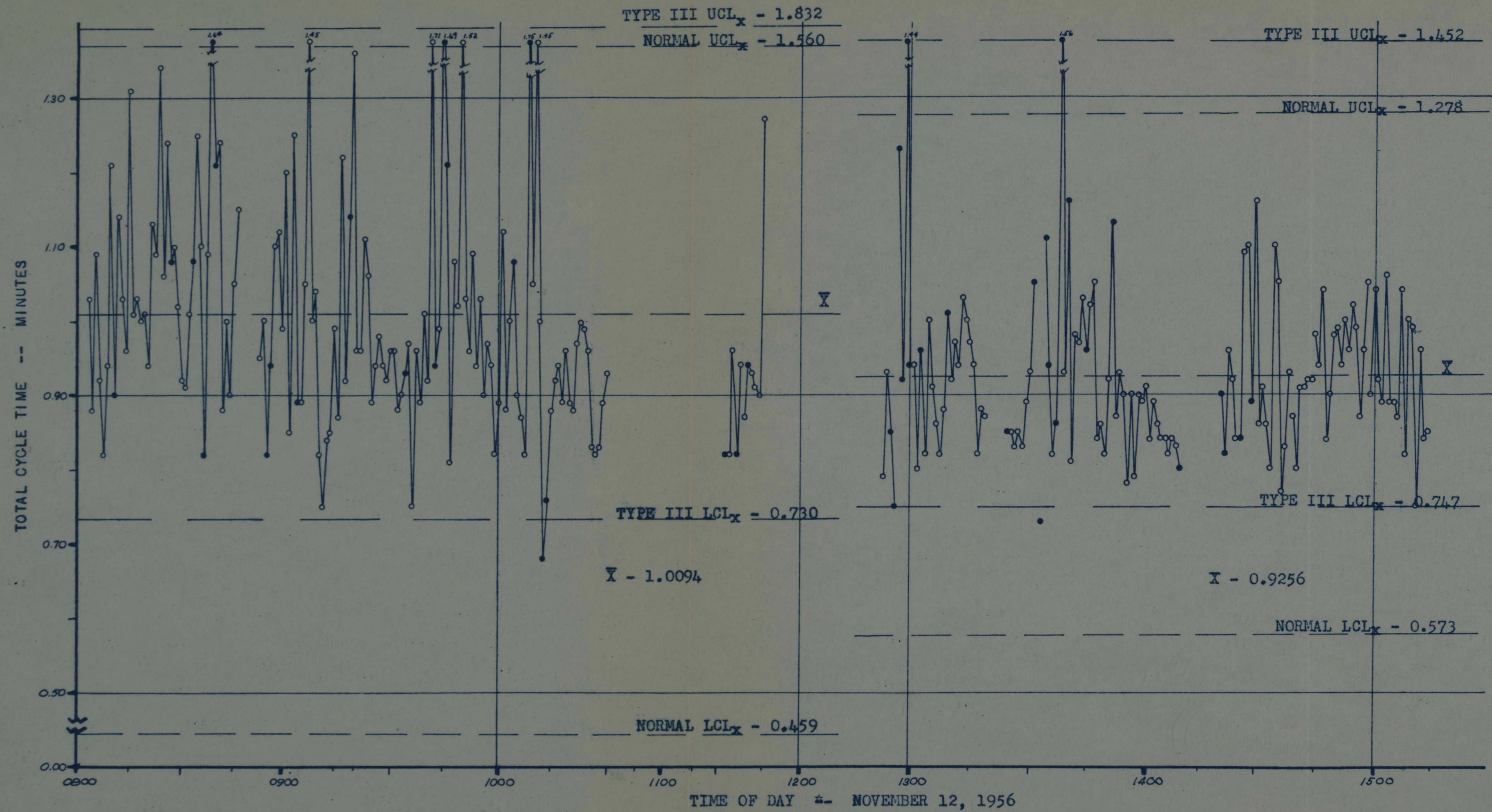


Fig. 15. Total Cycle Time Control Chart - Operator A - Monday

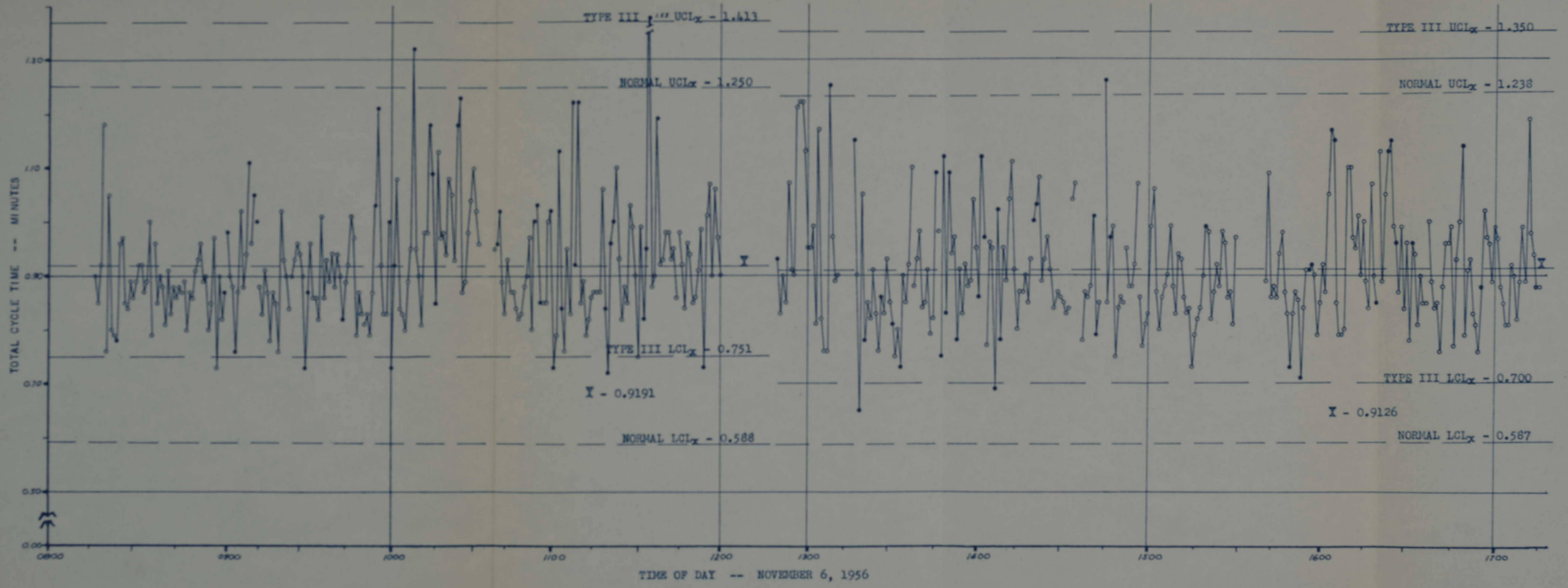


Fig. 16. Total Cycle Time Control Chart - Operator A - Tuesday

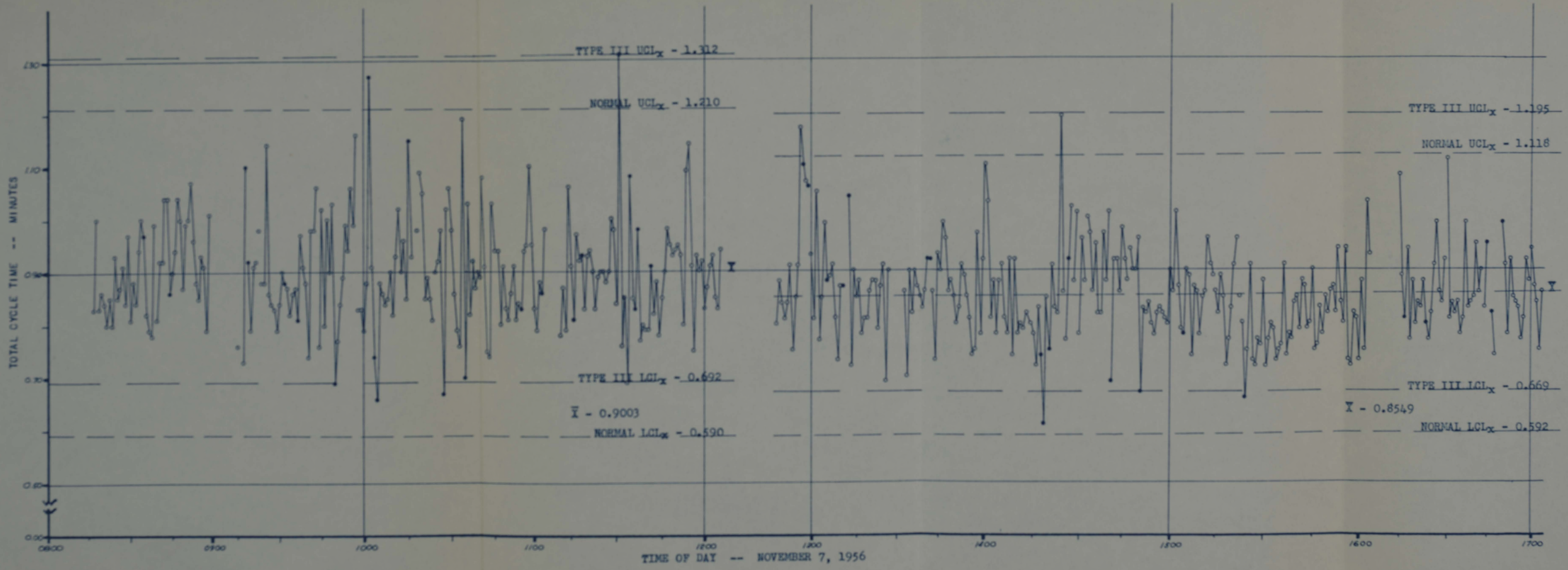


Fig. 17. Total Cycle Time Control Chart - Operator A - Wednesday

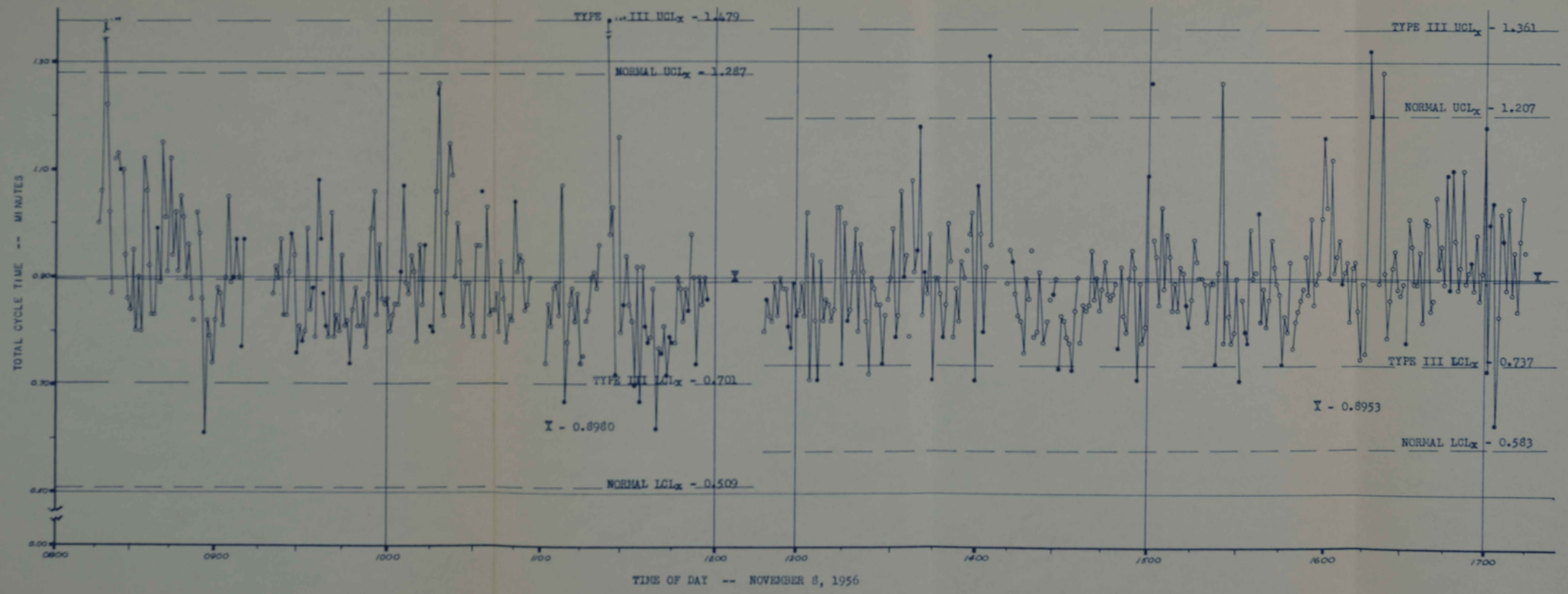


Fig. 18. Total Cycle Time Control Chart - Operator A - Thursday

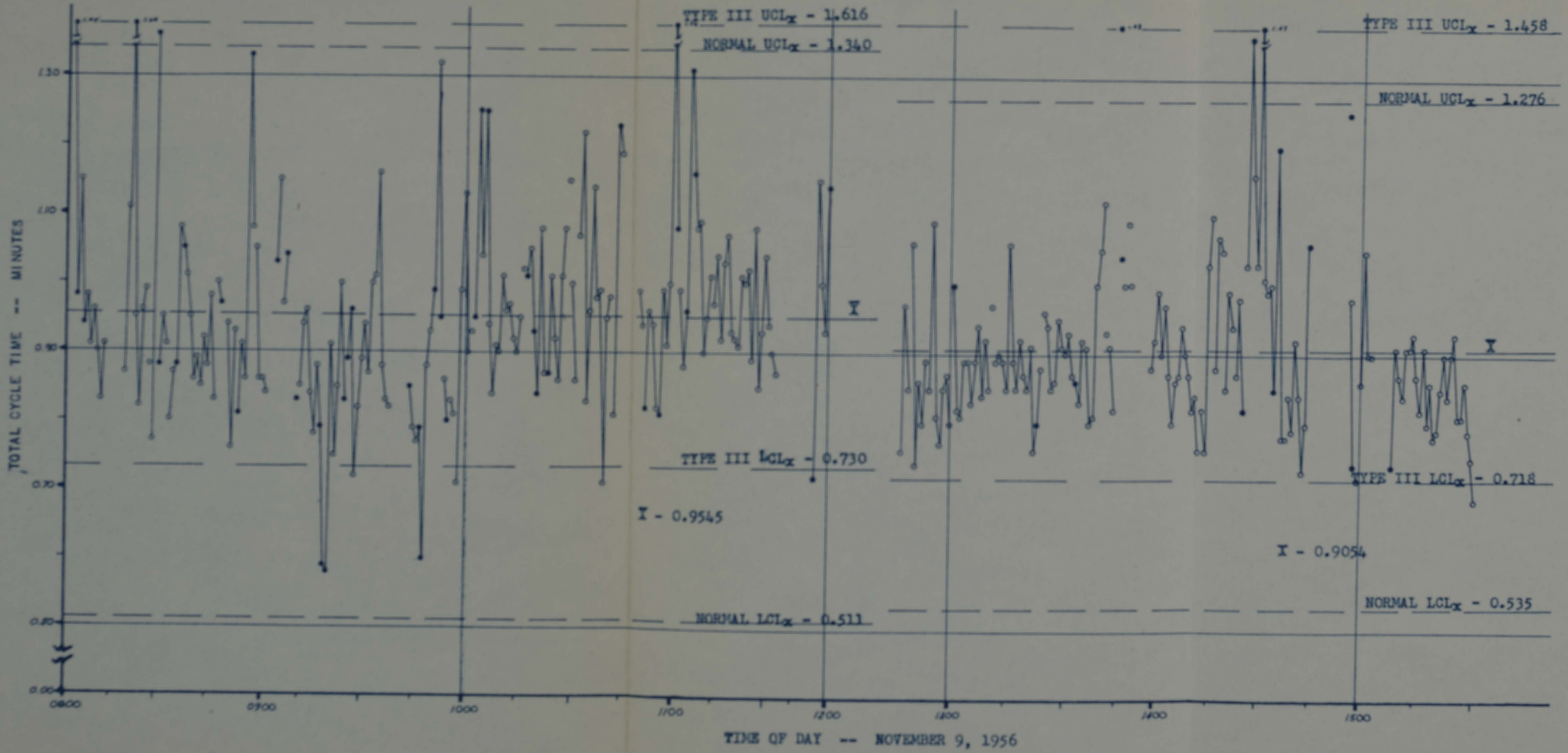


Fig. 19. Total Cycle Time Control Chart - Operator A - Friday

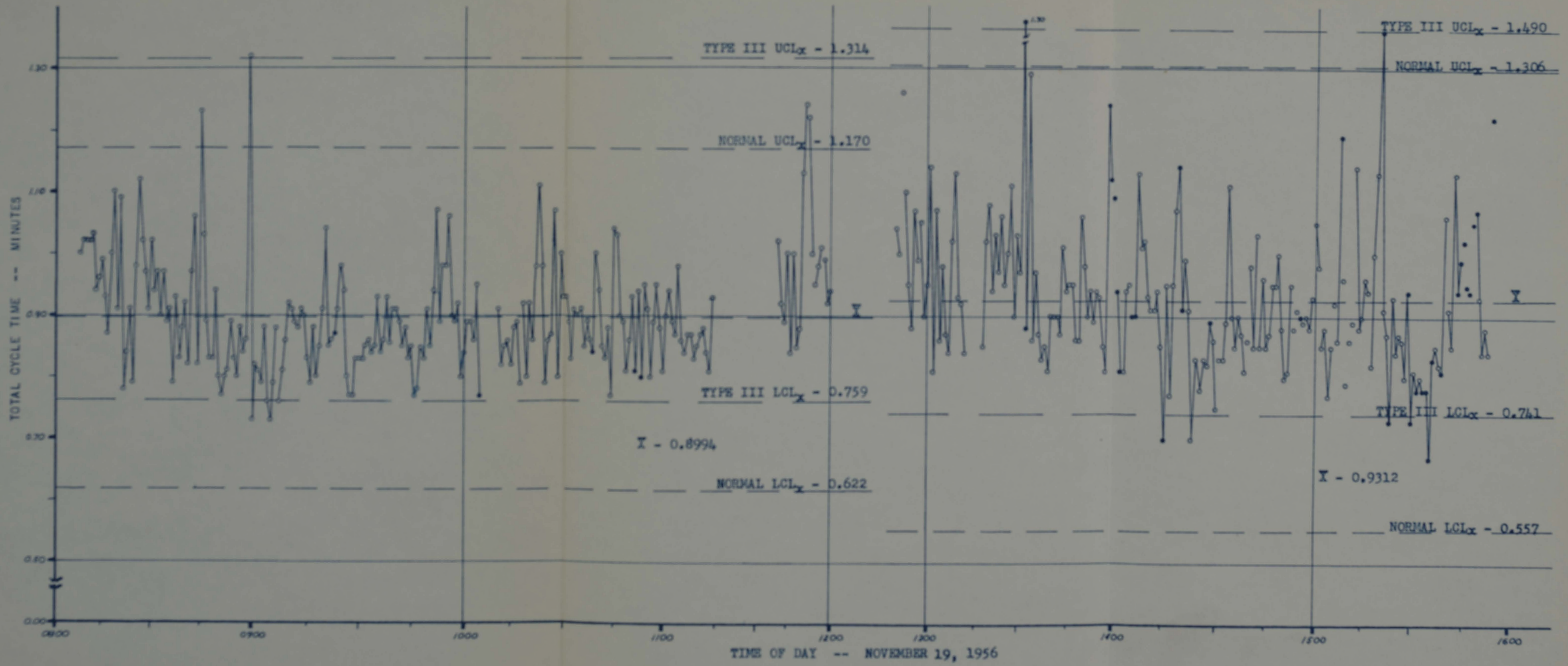


Fig. 20. Total Cycle Time Control Chart - Operator B - Monday

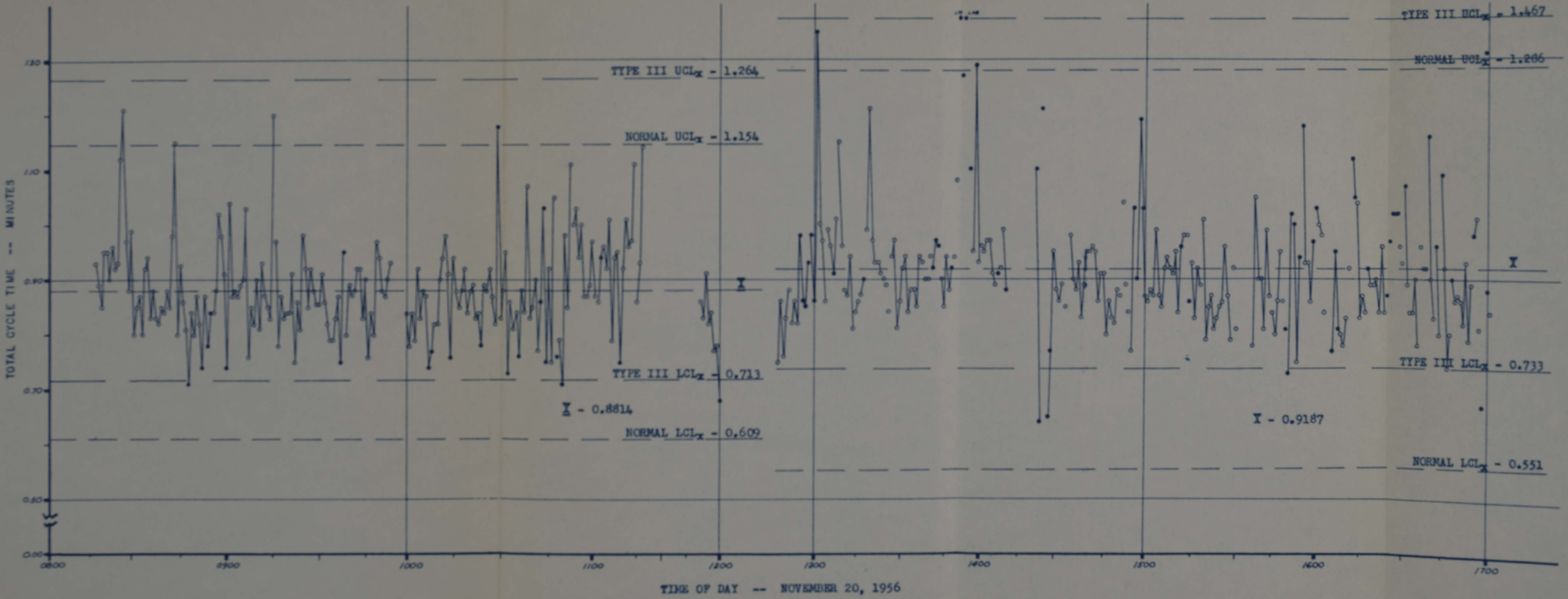


Fig. 21. Total Cycle Time Control Chart - Operator B - Tuesday

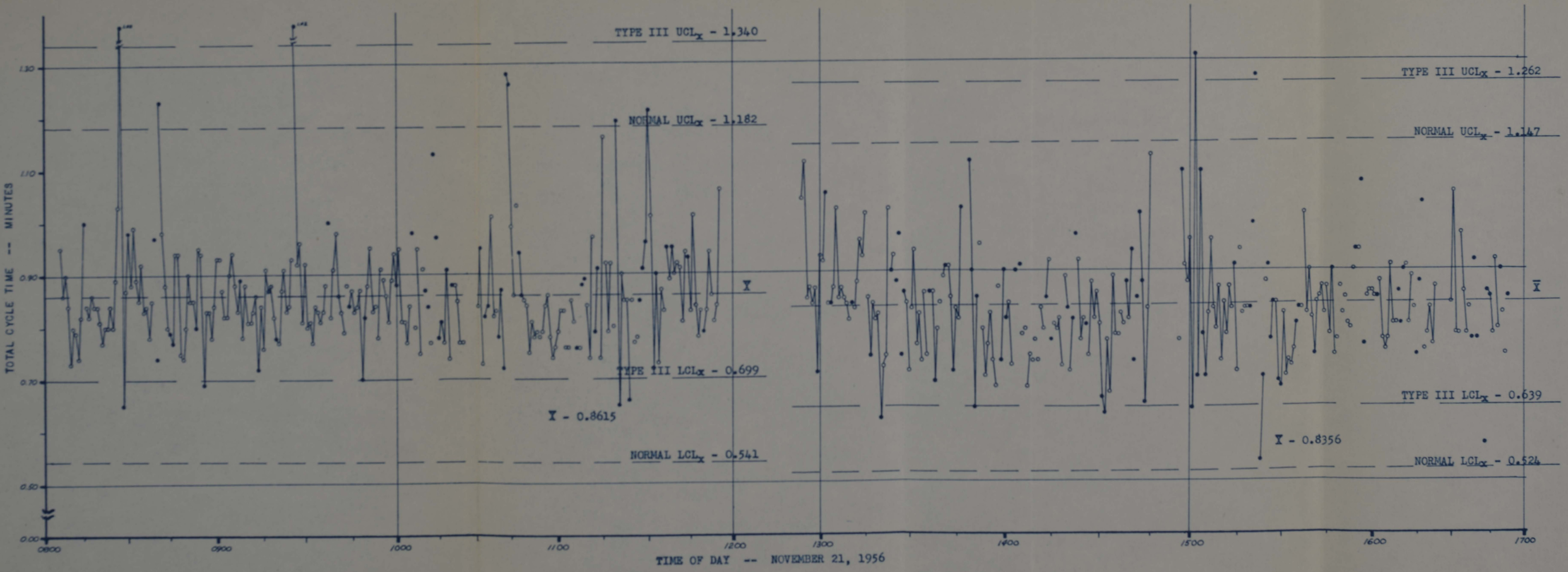


Fig. 22. Total Cycle Time Control Chart - Operator B - Wednesday

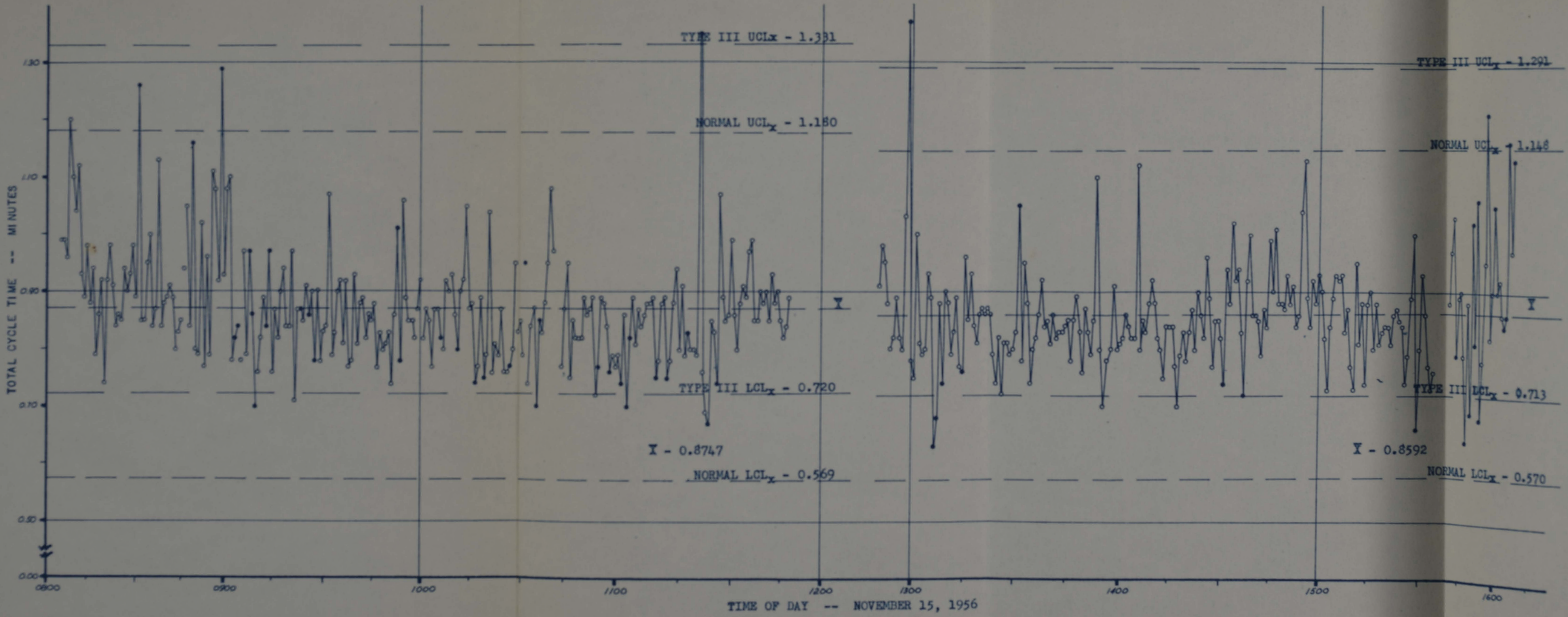


Fig. 23. Total Cycle Time Control Chart - Operator B - Thursday

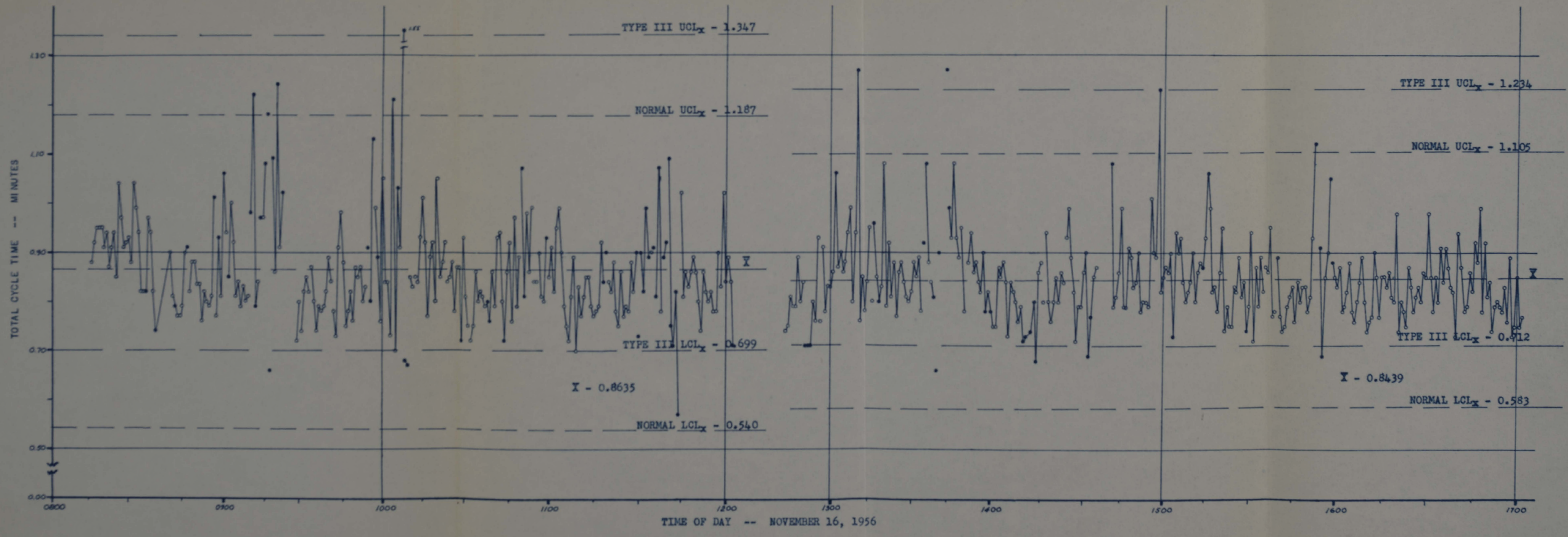


Fig. 24. Total Cycle Time Control Chart - Operator B - Friday

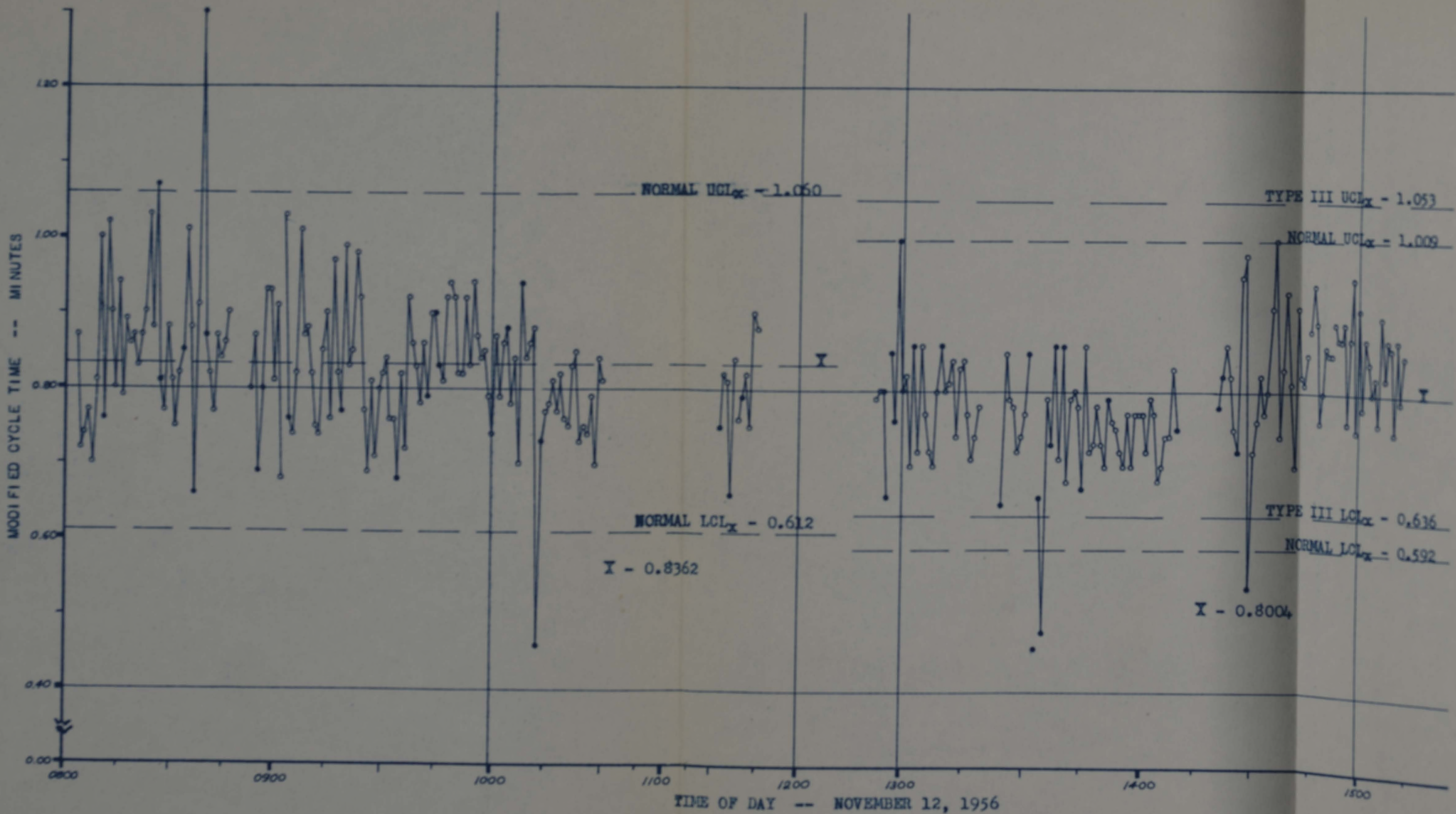


Fig. 25. Modified Cycle Time Control Chart - Operator A - Monday

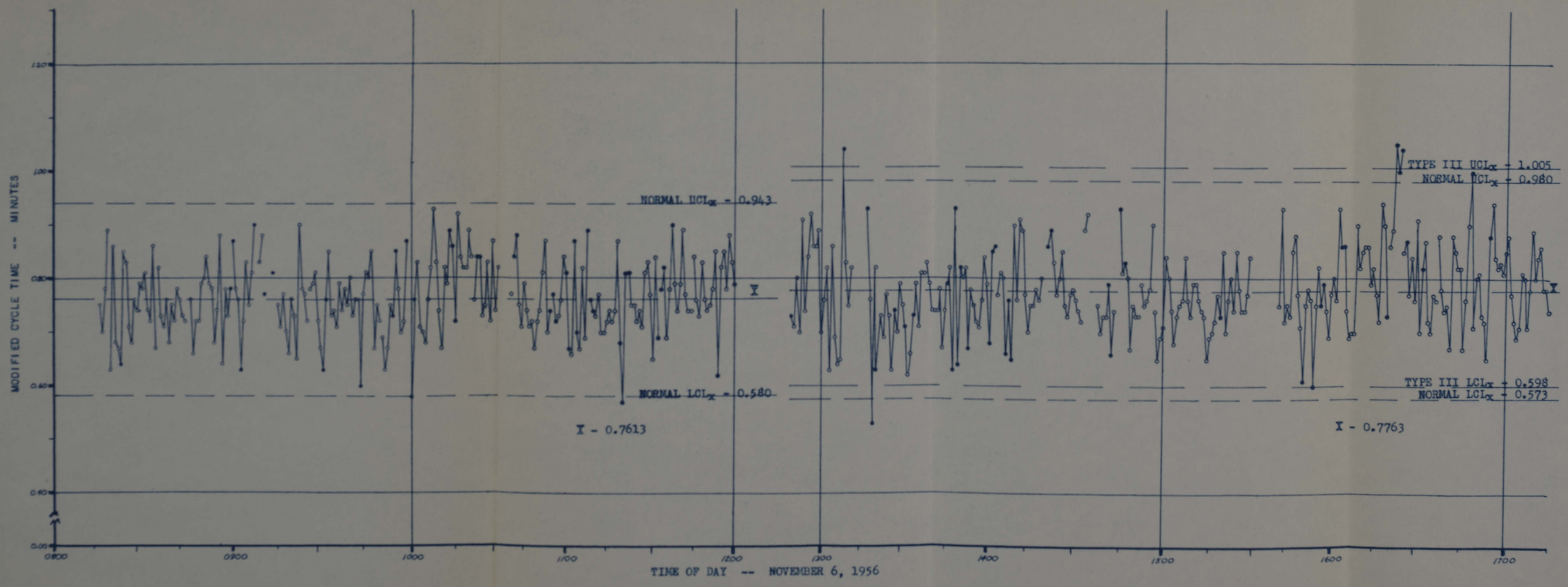


Fig. 26. Modified Cycle Time Control Chart - Operator A - Tuesday

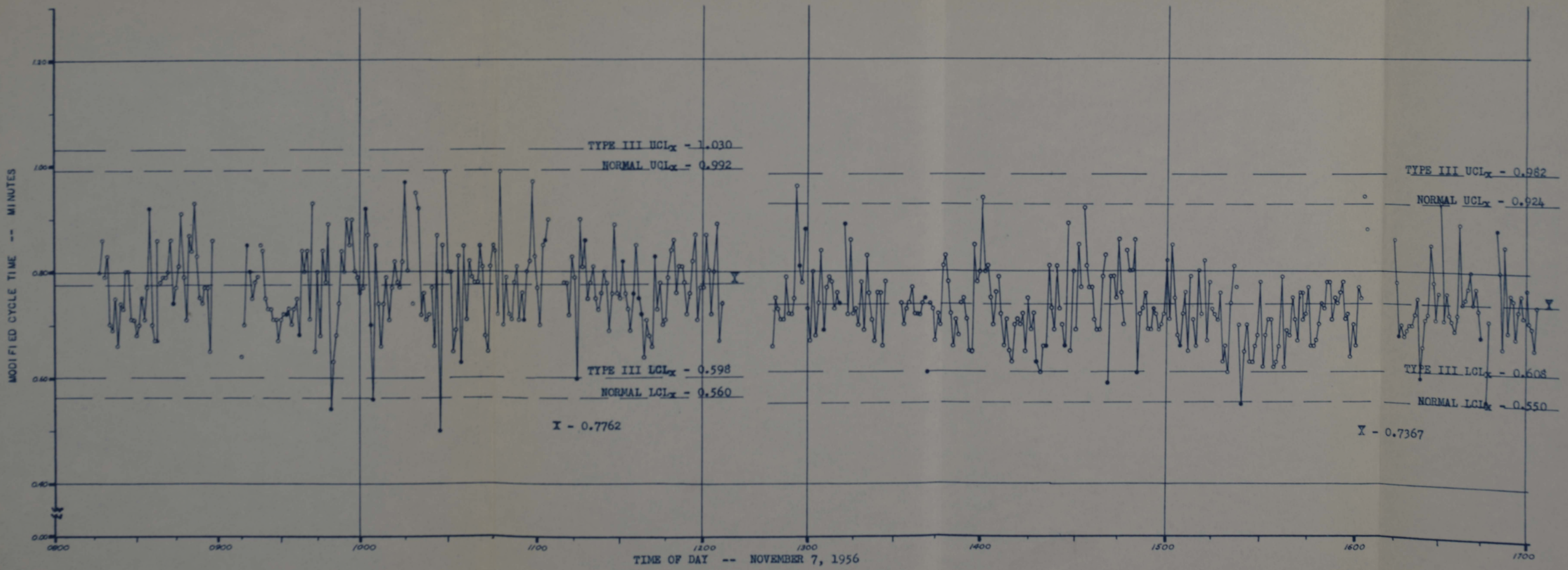


Fig. 27. Modified Cycle Time Control Chart - Operator A - Wednesday

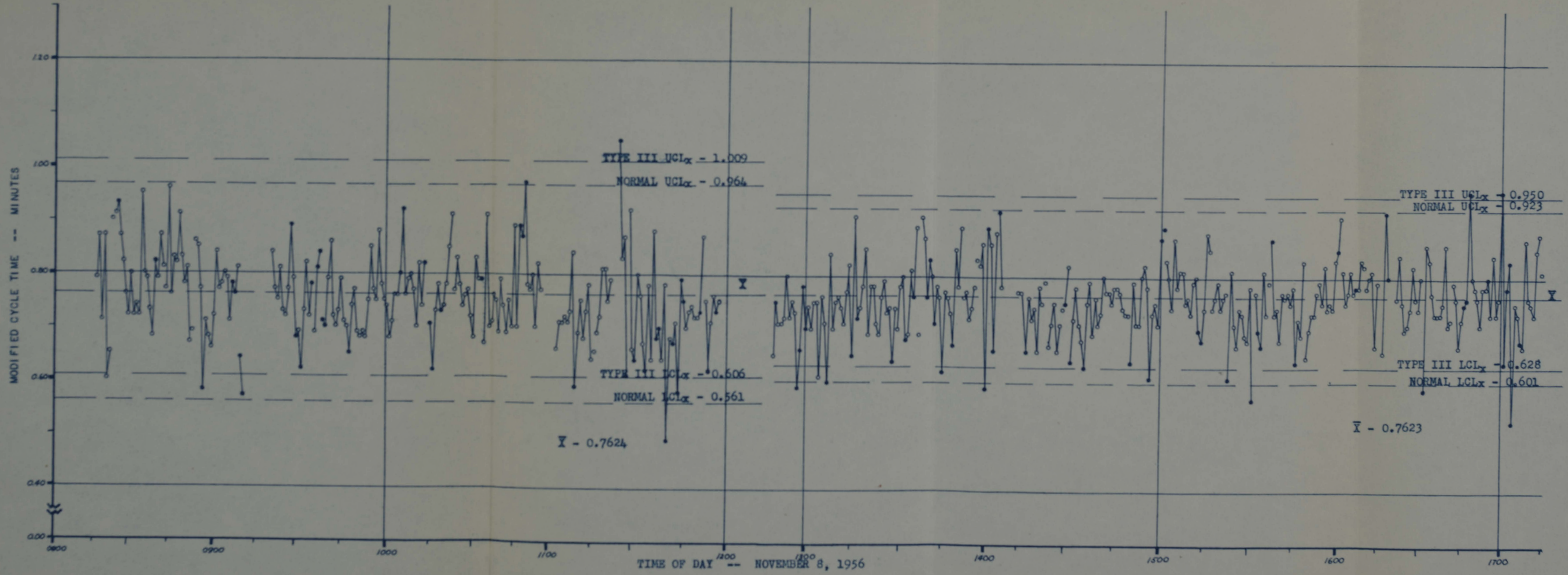


Fig. 28. Modified Cycle Time Control Chart - Operator A-- Thursday

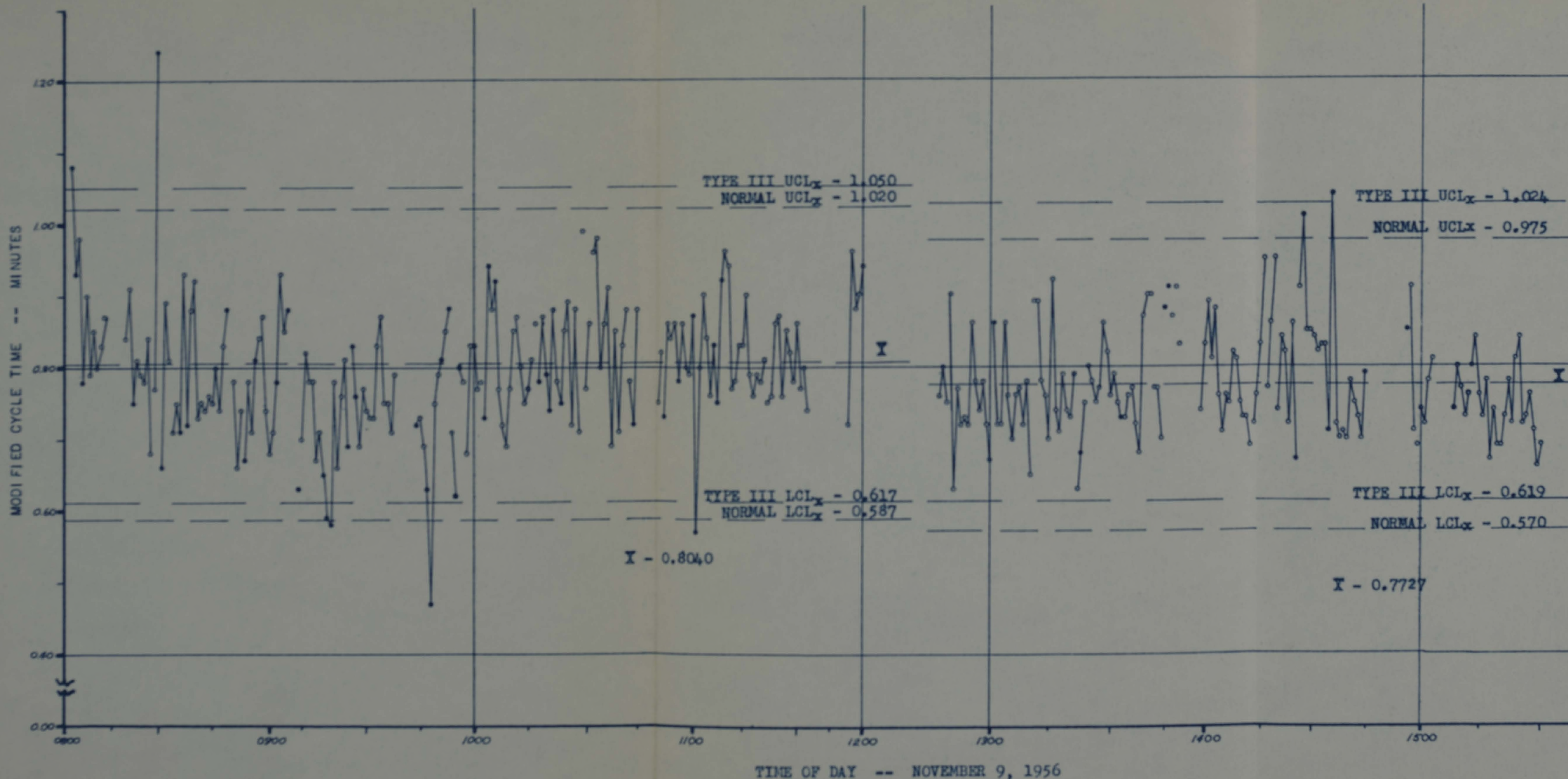


Fig. 29. Modified Cycle Time Control Chart - Operator A - Friday

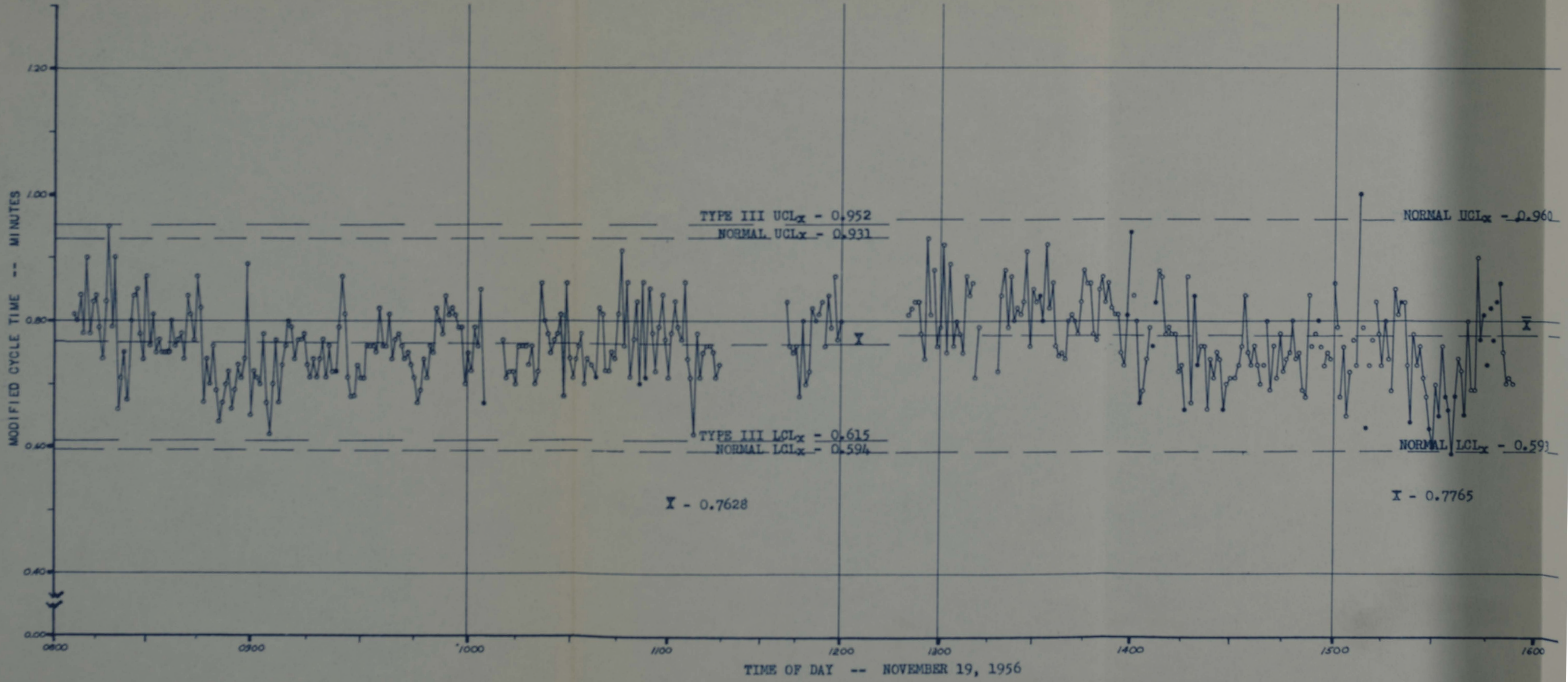


Fig. 30. Modified Cycle Time Control Chart - Operator B - Monday

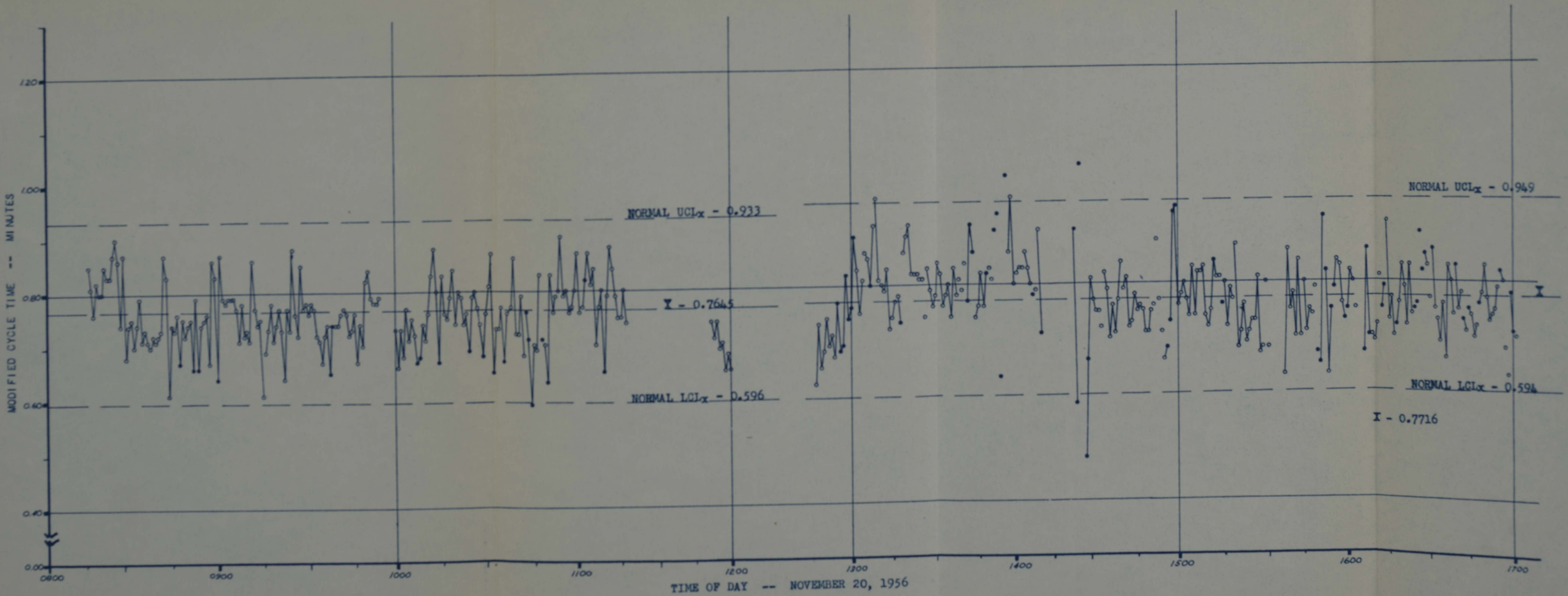


Fig. 31. Modified Cycle Time Control Chart - Operator B - Tuesday

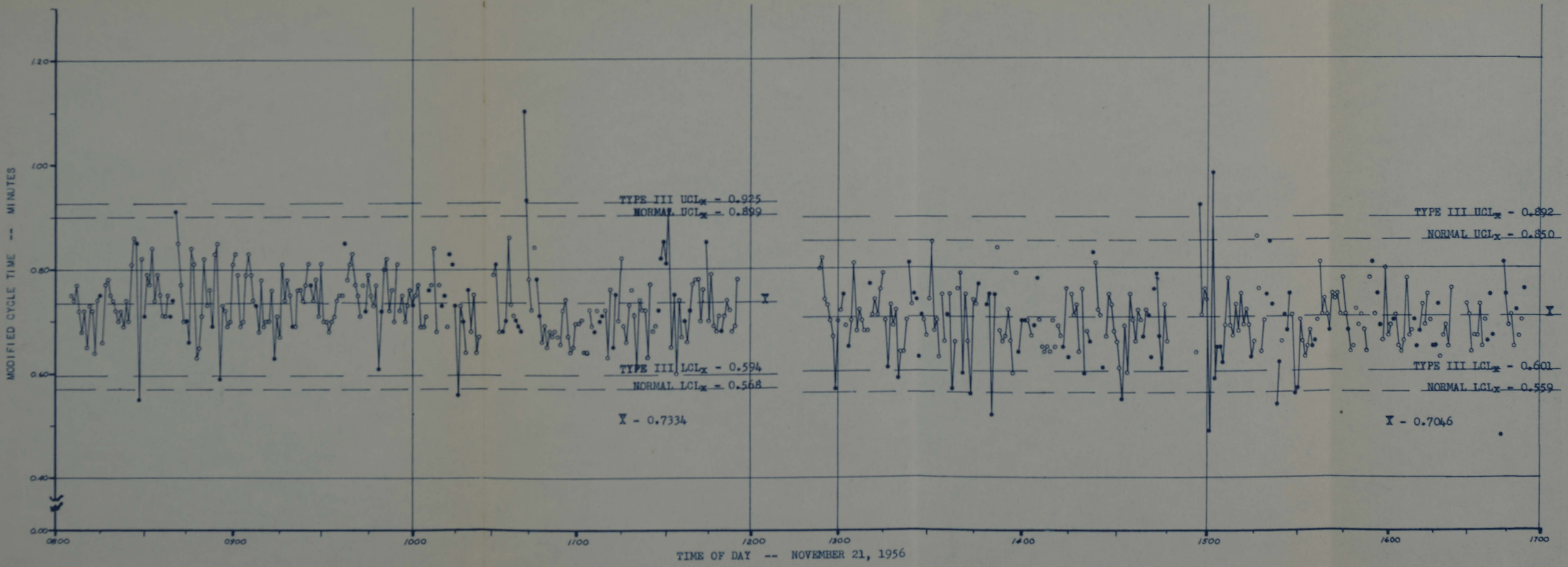


Fig. 32. Modified Cycle Time Control Chart - Operator B - Wednesday

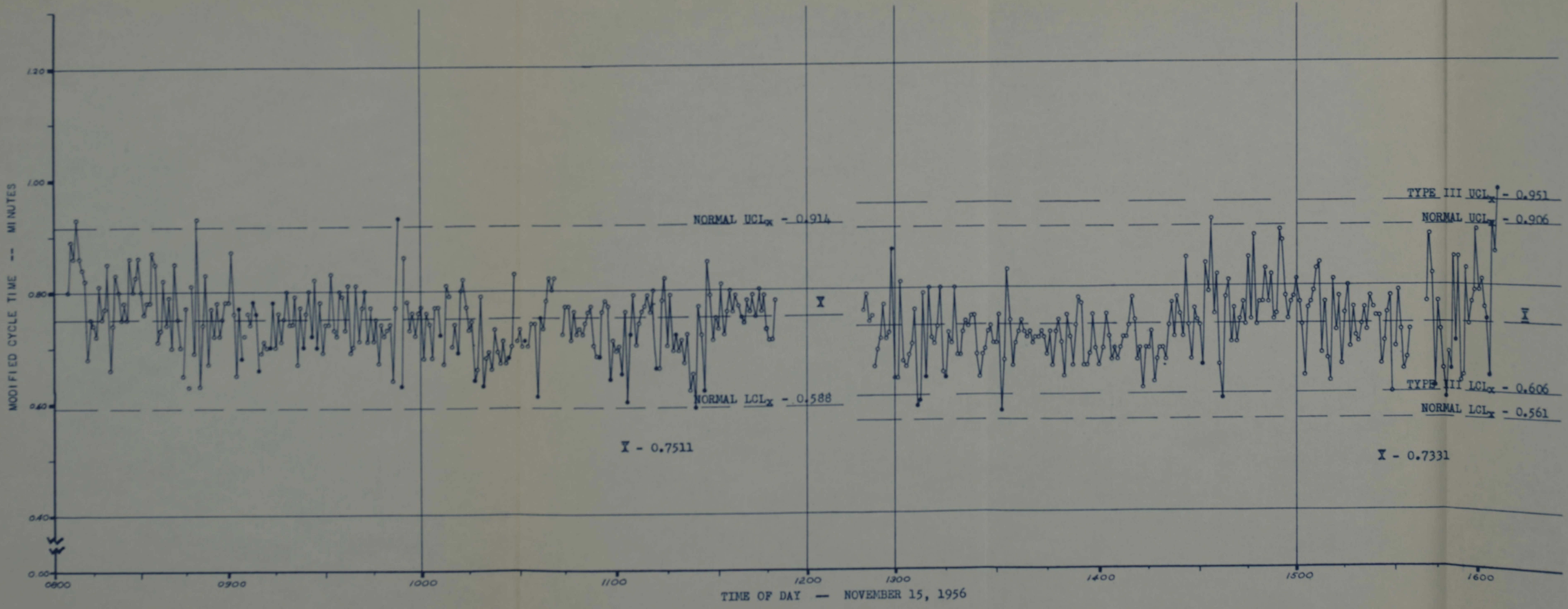


Fig. 33. Modified Cycle Time Control Chart - Operator B - Thursday

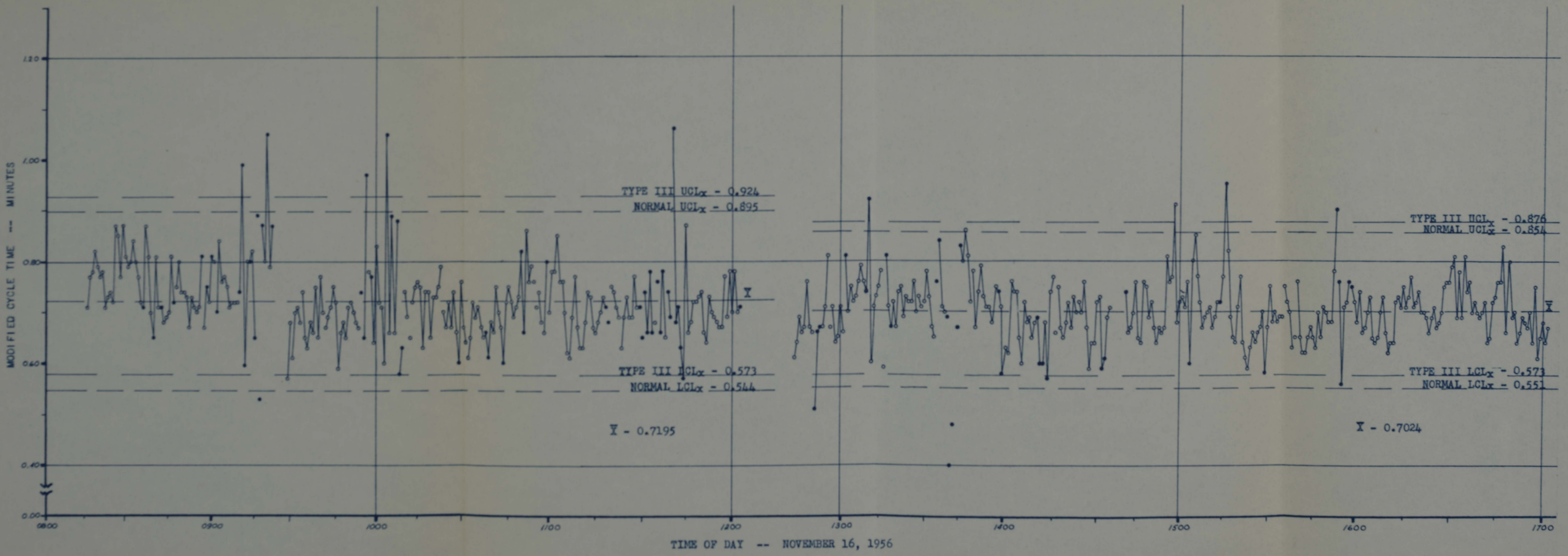
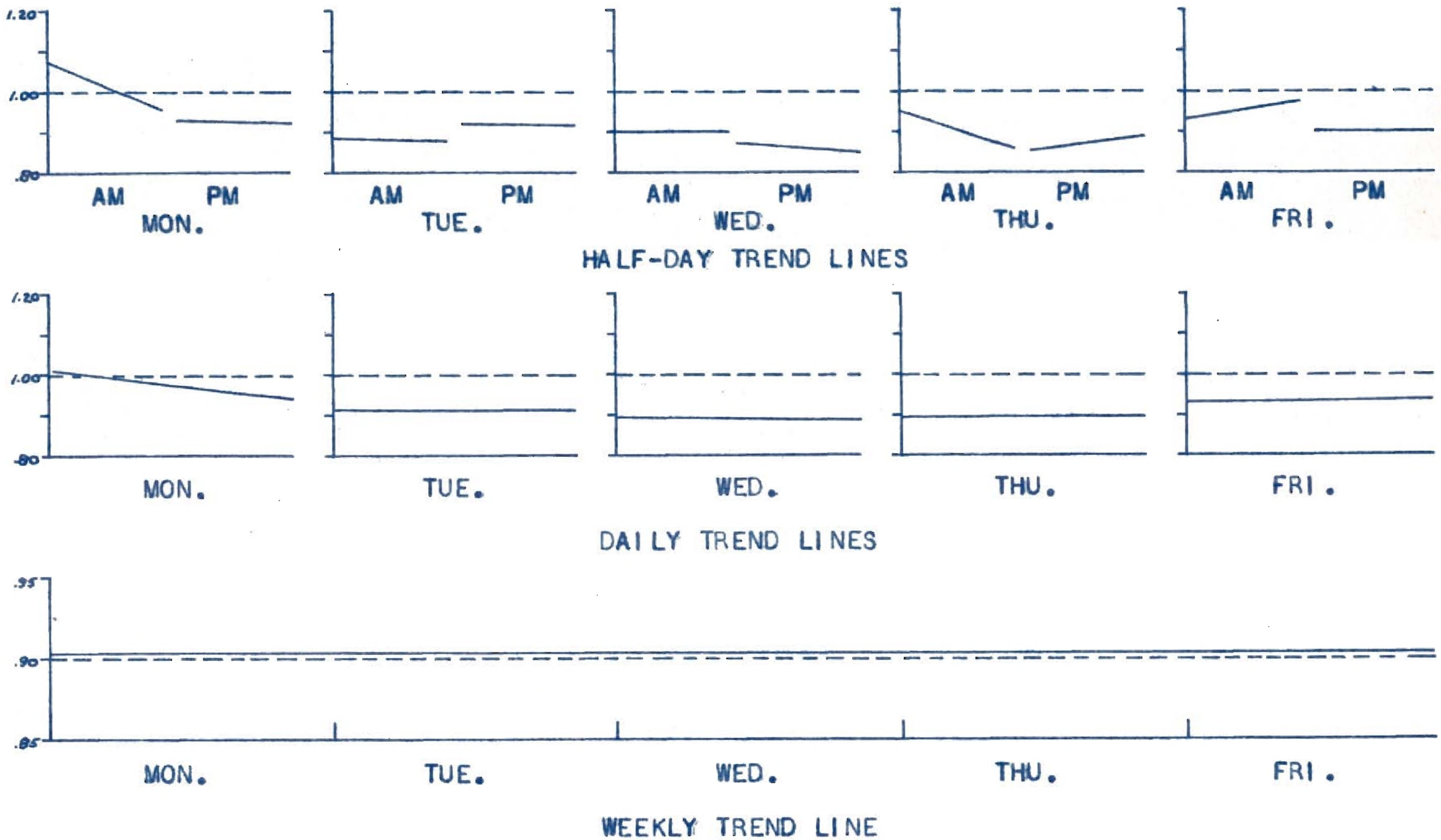


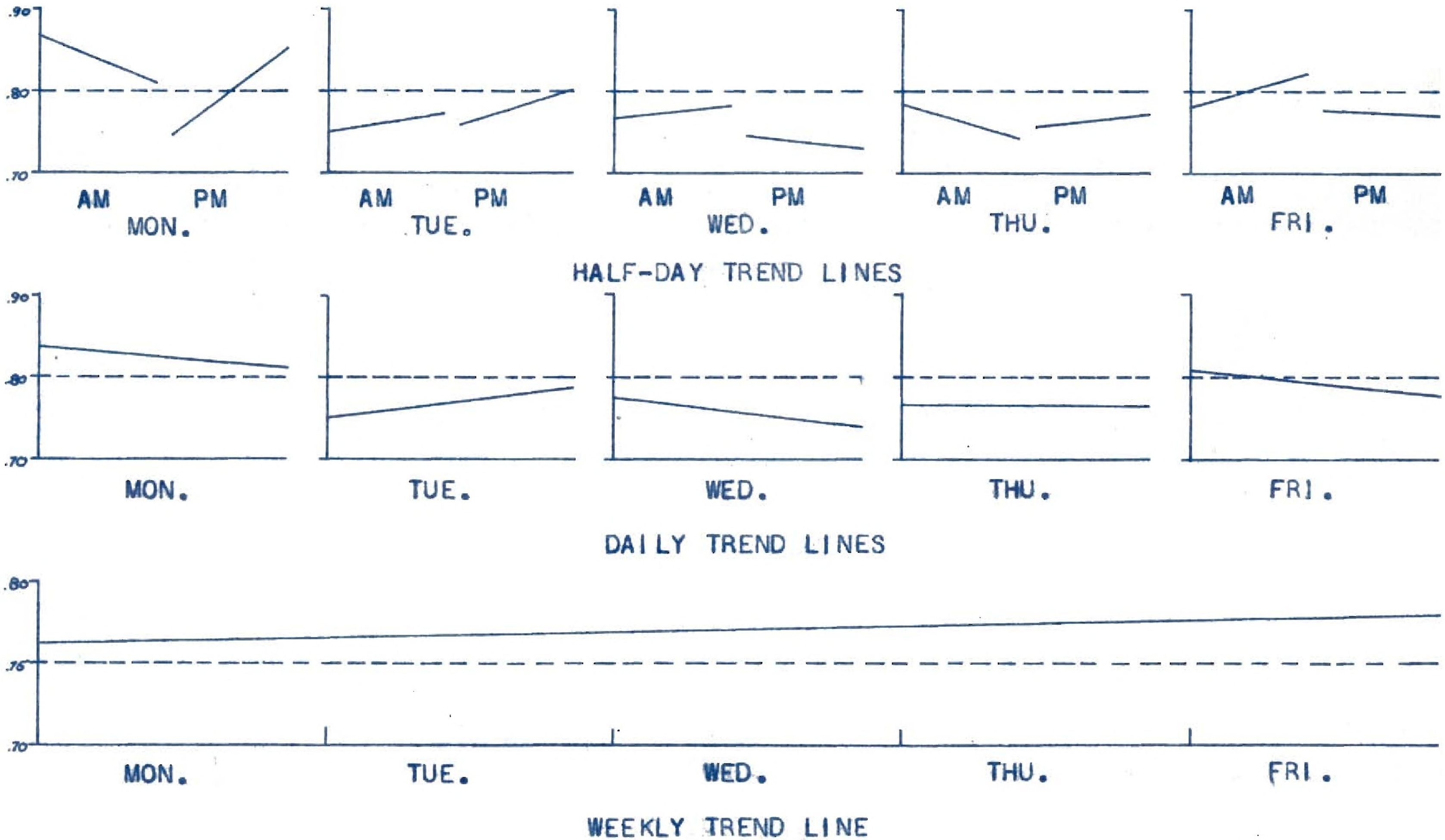
Fig. 34. Modified Cycle Time Control Chart - Operator B - Friday

A P P E N D I X C



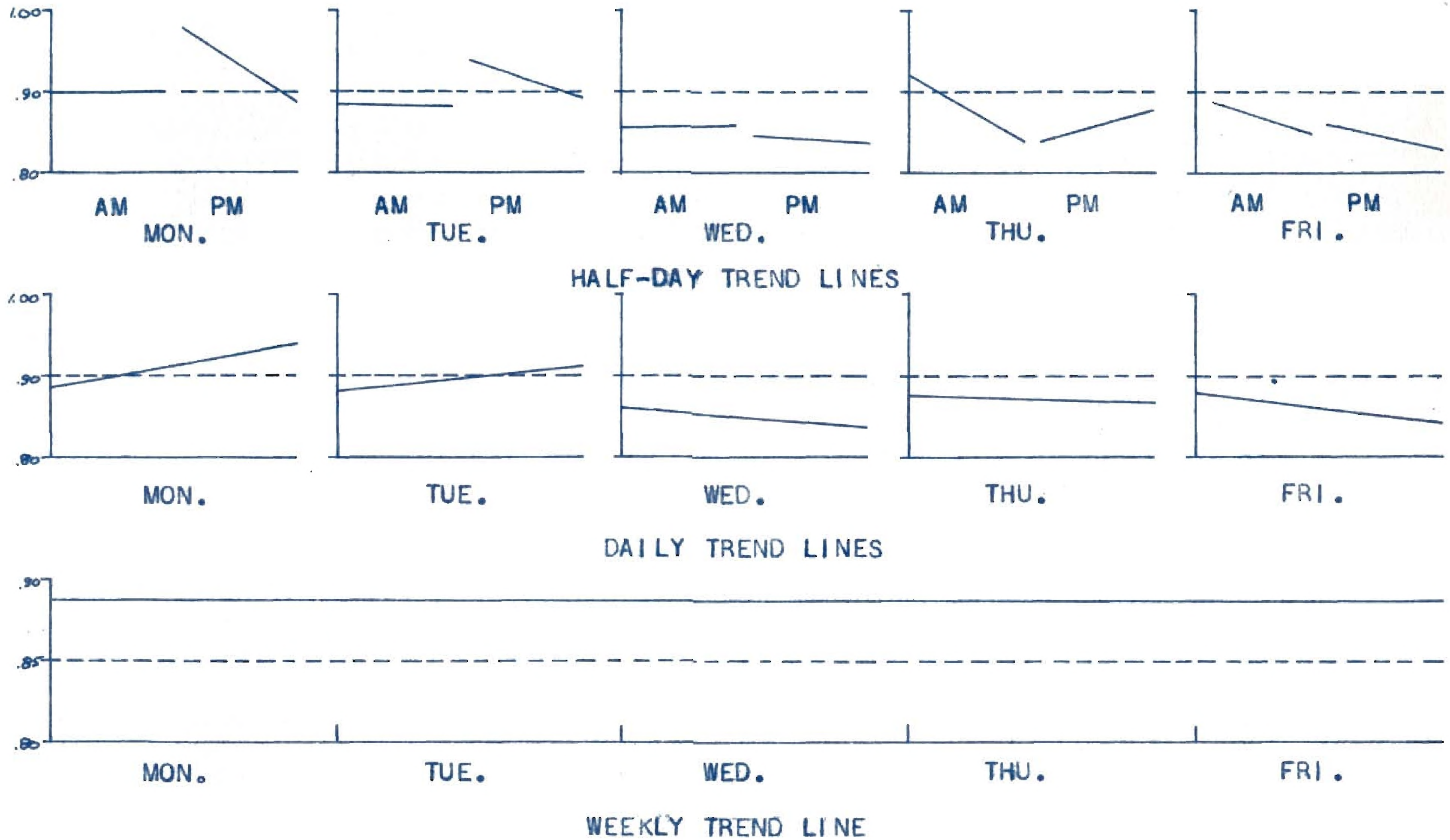
ORDINATE - CYCLE TIME - MIN. ABSCISSA - TIME OF DAY

FIG. 35. HALF-DAY, DAILY, AND WEEKLY LINEAR TREND LINES FOR TOTAL CYCLE TIME SERIES - OPERATOR A



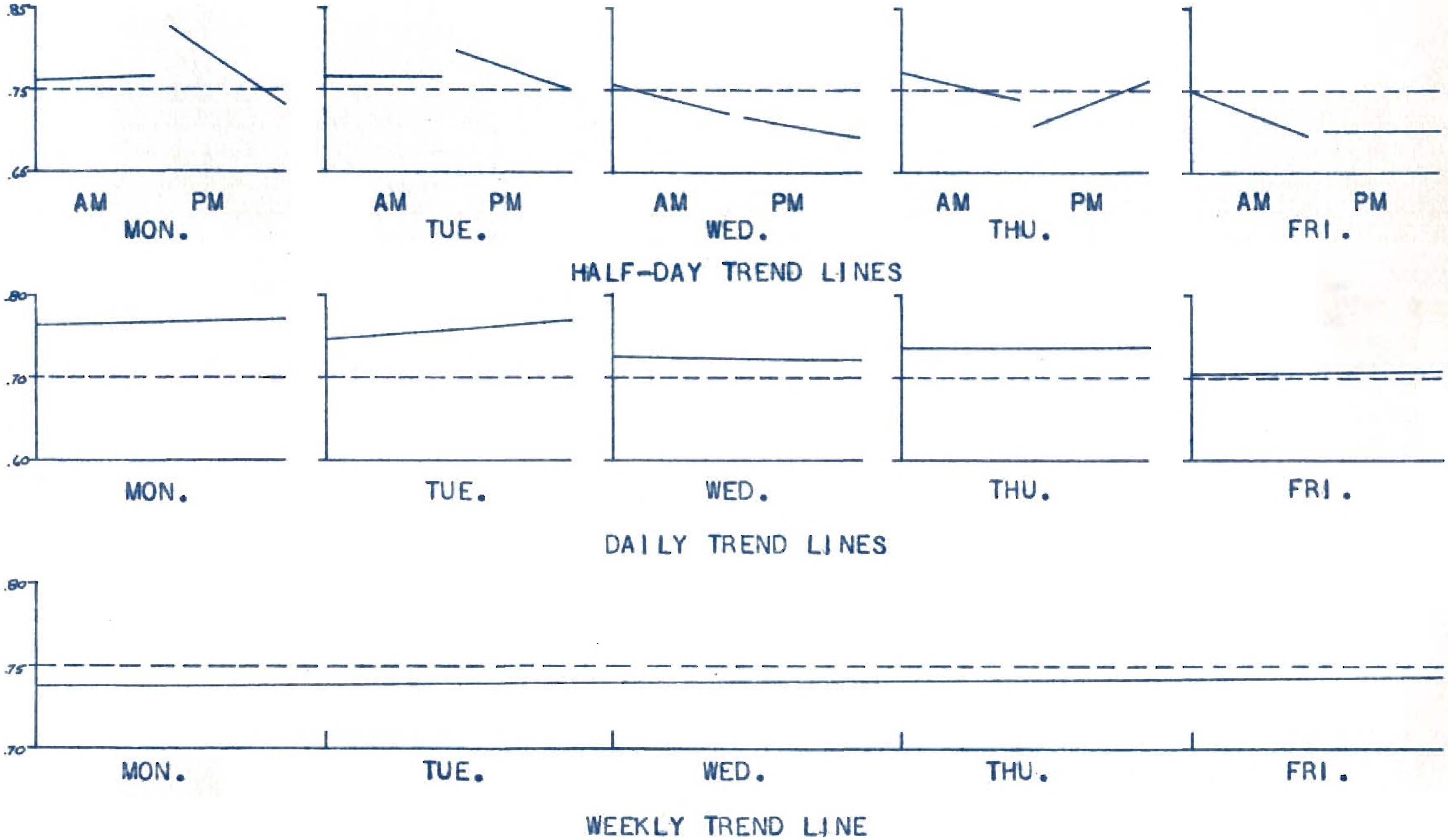
ORDINATE - CYCLE TIME - MIN. ABSCISSA - TIME OF DAY

FIG. 36. HALF-DAY, DAILY, AND WEEKLY LINEAR TREND LINES FOR MODIFIED CYCLE TIME SERIES - OPERATOR A



ORDINATE - CYCLE TIME - MIN. ABSCISSA - TIME OF DAY

FIG. 37. HALF-DAY, DAILY, AND WEEKLY LINEAR TREND LINES FOR TOTAL CYCLE TIME SERIES - OPERATOR B



ORDINATE - CYCLE TIME - MIN. ABSCISSA - TIME OF DAY

FIG. 38. HALF-DAY, DAILY, AND WEEKLY LINEAR TREND LINES FOR MODIFIED CYCLE TIME SERIES - OPERATOR B

Table 19. Equations of Linear Trend Lines for Cycle Time Series

Period	Equation	Equation
	Total Cycle Time Series	Modified Cycle Time Series
	Operator A	
Mon.-AM	x = 1.0731 - 0.000866t	x = 0.8679 - 0.000502t
PM	x = 0.9309 - 0.000081t	x = 0.7470 + 0.000989t
Tue.-AM	x = 0.8859 - 0.000290t	x = 0.7490 + 0.000131t
PM	x = 0.9158 - 0.000024t	x = 0.7596 + 0.000151t
Wed.-AM	x = 0.9012 - 0.000008t	x = 0.7687 + 0.000074t
PM	x = 0.8727 - 0.000132t	x = 0.7436 - 0.000055t
Thu.-AM	x = 0.9540 - 0.000516t	x = 0.7851 - 0.000260t
PM	x = 0.8572 + 0.000275t	x = 0.7558 + 0.000057t
Fri.-AM	x = 0.9278 + 0.000275t	x = 0.7816 + 0.000297t
PM	x = 0.9072 - 0.000025t	x = 0.7774 - 0.000069t
Mon.	x = 1.0137 - 0.000316t	x = 0.8350 - 0.000132t
Tue.	x = 0.9143 + 0.000005t	x = 0.7507 + 0.000092t
Wed.	x = 0.8921 - 0.000067t	x = 0.7735 - 0.000085t
Thu.	x = 0.8971 - 0.000003t	x = 0.7646 - 0.000011t
Fri.	x = 0.9267 + 0.000038t	x = 0.8077 - 0.000129t
Week	x = 0.9065 + 0.000005t	x = 0.7748 - 0.000001t
	Operator B	
Mon.-AM	x = 0.8982 + 0.000011t	x = 0.7605 + 0.000021t
PM	x = 0.9797 - 0.000513t	x = 0.8277 - 0.000648t
Tue.-AM	x = 0.8823 - 0.000009t	x = 0.7649 - 0.000004t
PM	x = 0.9389 - 0.000167t	x = 0.7956 - 0.000263t
Wed.-AM	x = 0.8567 + 0.000038t	x = 0.7554 - 0.000226t
PM	x = 0.8457 - 0.000081t	x = 0.7177 - 0.000154t
Thu.-AM	x = 0.9215 - 0.000373t	x = 0.7701 - 0.000173t
PM	x = 0.8390 + 0.000183t	x = 0.7050 + 0.000281t
Fri.-AM	x = 0.8957 - 0.000255t	x = 0.7499 - 0.000304t
PM	x = 0.8602 - 0.000113t	x = 0.7070 - 0.000036t
Mon.	x = 0.8873 + 0.000131t	x = 0.7614 + 0.000038t
Tue.	x = 0.8797 + 0.000098t	x = 0.7431 + 0.000137t
Wed.	x = 0.8593 - 0.000043t	x = 0.7289 - 0.000049t
Thu.	x = 0.8774 - 0.000042t	x = 0.7346 + 0.000038t
Fri.	x = 0.8793 - 0.000097t	x = 0.7036 + 0.000028t
Week	x = 0.8871 - 0.000001t	x = 0.7385 + 0.000002t

Operator B - Modified Cycle Distributions

$\sum 1/f_i = .0519$

$f = \sum^k f_i$

$f = 1960$

$1/f = .00051$

$\sum f_i \text{ Log } s_i^2 = -4925.14$

$c = 1 + \frac{1}{3(k-1)} \left(\sum^k 1/f_i - 1/f \right)$

$c = 1 + \frac{1}{3(9)} (.0519 - .0005)$

$c = 1.00190$

$s^2 = \frac{\sum f_i s_i^2}{\sum f_i}$

$s^2 = \frac{6.1010}{1960}$

$s^2 = .003113$

$\text{Log } s^2 = -2.50685$

$f \text{ Log } s^2 = -4913.43$

$\chi^2 = \frac{2.3026}{c} (f \text{ Log } s^2 - \sum f_i \text{ Log } s_i^2)$

$\chi^2 = \frac{2.3026}{1.0019} (-4913.43 - (-4925.14))$

$\chi^2 = 26.925$

Degrees of Freedom = k-1 = 10-1 = 9

Level of Significance = .005

Fig. 39. Sample Calculations for Bartlett's Test for Homogeneity of Variances

BIBLIOGRAPHY

1. Barbash, J., Labor Unions in Action, New York: Harper and Brothers, 1948, p. 73.

2. Gomberg, W. A., A Trade Union Analysis of Time Study, 1st ed., Chicago: Science Research Associates, 1948, p. 4.

3. Gomberg, W. A., A Trade Union Analysis of Time Study, 2nd ed., New York: Prentice-Hall, Inc., 1955, pp. 52-53.

4. Presgrave, R., The Dynamics of Time Study, Toronto: Toronto University Press, 1944, p. 3.

5. Gomberg, 2nd ed., op. cit., p. 142.

6. Shewhart, W. A., Economic Control of Quality of the Manufactured Product, New York: Van Nostrand Company, 1931, p. 437.

7. Lehrer, R. N., "Statistical Work Measurement Control," Advanced Management, Vol. 17, August, 1952, p. 10.

8. Loc. cit.

9. Seashore, R. H., "Work and Motor Performance," Handbook of Experimental Psychology, Stevens, S. S., editor, New York: John Wiley and Sons, Inc., 1951, p. 1360.

10. Muscio, B., "Is a Fatigue Test Possible?" British Journal of Psychology, Vol. 12, 1921, p. 45.

11. Viteles, M. S., Industrial Psychology, New York: W. W. Norton and Company, Inc., 1932, p. 447.

12. Rothe, H. F., "Output Rates Among Butterwrappers: I. Work Curves and Their Stability," Journal of Applied Psychology, Vol. 30, 1946, p. 210.

13. Ryan, T. A., Work and Effort, New York: The Ronald Press, 1947, p. 75.

14. Bartley, S. H. and Chute, E., Fatigue and Impairment in Man, New York: McGraw-Hill Book Company, Inc., 1947, p. 49.

15. Davis, L. E. and Josselyn, P. D., "An Analysis of Work Decrement Factors in a Repetitive Industrial Operation," Advanced Management, Vol. 18, April, 1953, p. 8.

16. Wiberg, M., "Work Time Analysis," Personnel Journal, Vol. 19, December, 1940, p. 219.

17. Ibid., p. 220.

18. Gomberg, 1st ed., op. cit.

19. Abruzzi, A., Work Measurement, New York: Columbia University Press, 1952, p. 106.

20. Ibid., p. 107.

21. Maynard, H. B., Stegemerten, G. J., and Schwab, J. L., Methods Time Measurement, New York: McGraw-Hill Book Company, Inc., 1948.

22. Quick, J. H., Shea, W. J., and Koehler, R. E., "Motion-Time Standards," Factory Management and Maintenance, Vol. 103, May, 1945, pp. 97-108.

23. Lynch, H., "Basic Motion Timestudy," Journal of Industrial Engineering, Vol. VI, August, 1953, p. 4.

24. Segur, A. B., "Motion Time Analysis," Proceedings of the Time and Motion Study Clinic, Chicago: The Industrial Management Society, November, 1938.

25. Holmes, W. G., Applied Time and Motion Study, New York: The Ronald Press, 1938.

26. Barnes, R. M. and Mundel, M. E., "Studies of Hand Motions and Rhythm Appearing in Factory Work," University of Iowa Studies in Engineering, Bulletin No. 12, Iowa City: University of Iowa Press, 1938.

27. Nadler, G. and Wilkes, J. W., "Studies in Relationships of Therbligs," Advanced Management, Vol. 18, No. 2, February, 1953, p. 20.

28. Nadler, G. and Denholm, D. H., "Therblig Relationships," Journal of Industrial Engineering, Vol. VI, No. 2, March-April, 1955, pp. 3-4, 23.

29. Perkins, F. T., An Investigation of the Independence of Time Study Elements, Unpublished M.S. Thesis, Georgia Institute of Technology, 1956.

30. Green, E. W., An Analysis of the Characteristics of Element-Time Distribution, Unpublished M.S. Thesis, Georgia Institute of Technology, 1955.

31. Barnes, R. M., Motion and Time Study, 3rd ed., New York: John Wiley and Sons, Inc., 1949, pp. 354-363.

32. Davidson, H. O., *Functions and Bases of Time Standards*, Columbus, Ohio: American Institute of Industrial Engineers, Inc., 1952, pp. 327, 329.

33. *Ibid.*, p. 332.

34. *Ibid.*, p. 347.

35. *Ibid.*, pp. 394-395.

36. *Ibid.*, p. 396.

37. Lehrer, R. N. and Moder, J. J., "Mathematical Characteristics of Performance Times — A Preliminary Report," *American Institute of Industrial Engineers Conference Proceedings*, 1955, pp. 196-215.

38. *Ibid.*, p. 197.

39. Lind, W. E., *A Statistical Analysis of Work Time Distributions*, Unpublished M. S. Thesis, Georgia Institute of Technology, 1953, p. 67.

40. Taft, G. H., *Analysis of Work Time Distributions for a Short Cycle Manual Operation*, Unpublished M. S. Thesis, Georgia Institute of Technology, 1954.

41. *Ibid.*, p. 71.

42. Friedman, P. H., *A Study of Experimental Work-Time Distribution Characteristics to Determine the Existence of a Typical Distribution*, Unpublished M. S. Thesis, Georgia Institute of Technology, 1954.

43. *Ibid.*, p. 48.

44. McLeod, R. L. Jr., *A Control Chart Analysis of Cycle Performance Times*, Unpublished M. S. Thesis, Georgia Institute of Technology, 1954, pp. 77-78.

45. *Ibid.*, p. 80.

46. *Loc. cit.*

47. Summers, F. A., *The Relationship Between Stability of Cycle Performance Times and the Characteristics of the Work Time Distribution*, Unpublished M. S. Thesis, Georgia Institute of Technology, 1955, p. 40.

48. *Ibid.*, p. 41.

49. Muse, W. H., A Study of the Effects of Motivation on the Work-Time Distribution of an Operation on a Repetitive Manual Operation, Unpublished M. S. Thesis, Georgia Institute of Technology, 1956.

50. Rogers, N. K., A Study of Work Time Distribution Characteristics and Their Relationship to Delay Time Distribution Characteristics for Several Operators During Similar Work Periods, Unpublished M. S. Thesis, Georgia Institute of Technology, 1956.

51. Muse, op. cit., p. 50.

52. Rogers, op. cit., p. 60.

53. Ibid., p. 61.

54. Ibid., p. 62.

55. Spaeth, R. A., "Prevention of Fatigue in Industry," Journal of Industrial Hygiene, 1919-1920, p. 435.

56. Hald, A., Statistical Theory with Engineering Applications, New York: John Wiley and Sons, Inc., 1952, pp. 342-349.

57. Ibid., pp. 357-358.

58. Salvosa, L. R., "Table I - Areas of the Standardized Type III Function," Annals of Mathematical Statistics, Vol. 1, 1930, pp. 191ff.

59. Hald, op. cit., p. 291.

60. Ibid., pp. 447-449.

61. Duncan, D. B., "Multiple Range and Multiple F Tests," Biometrics, Vol. II, No. 1, March, 1955, pp. 1ff.

62. Geary, R. C. and Pearson, E. S., Tests of Normality, London: Biometrika Office, University College, 1938, pp. 7-9.