A CONTROL CHART ANALYSIS
OF CYCLE PERFORMANCE TIMES

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Robert Lawrence McLeod, Jr.

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ABSTRACT

One reason time study lacks scientific validity is because it is based on an unsound theoretical model. This model has been previously thought of as a normal distribution of times, but recent studies tend to refute this. Before the exact nature of this model can be determined, it is necessary to prove the existence of a state of statistical control within these times.

The purpose of this study was to investigate some of the critical factors influencing this state of statistical control in work performance times. These factors were to take the form of certain assignable or identifiable causes of variation in cycle performance times from a manual, repetitive-type assembly operation. The effect on the stability of the times when these variables were removes was of principal interest.

Control charts for means and standard deviations of a considerable amount of cycle time data were prepared first. All data containing any of six variables previously identified by micromotion analysis of the operation were then removed. New control charts were plotted with the remaining data.

Analysis of the stability of both sets of charts was performed, utilizing three-sigma control limits as the criterion for stability.

Evaluation of the significant changes appearing in the latter charts presented inconclusive evidence that the removal of the assignable causes of variation selected significantly affects the statistical stability of cycle performance times as studied. Additional conclusions were (1) that the presence in time data of certain assignable causes of variation may or may not be indicated on control charts, (2) that work times are not unstable solely on account of the presence of these variables and, (3) that micromotion analysis fails to completely identify all factors influencing work-times from manual operations.

It was recommended that further study be directed toward the psychological and personal history characteristics of consistently "stable" operators, the appropriateness of ordinary statistical quality control techniques in work measurement studies, and the influence of work pace or level of performance on cycle times.

CHAPTER I

INTRODUCTION

Time study as generally practiced has received widespread industrial acceptance, but this acceptance has been with question, reluctance, and hostility. As might be expected with the founding of any "new science", this opposition arose simultaneously with Frederick W. Taylor's pioneering of the scientific management movement. It increased greatly during the "efficiency expert" era, and lingers on even today, though somewhat to a lesser extent.

Current opposition to time study takes many varied forms. Ralph Presgrave summarizes by stating that "opposition to time study arises, first, from the natural conservatism of the worker and his mistrust for that which is new and mysterious, and, second, from the manner in which time study has been applied, or misapplied" (1). Granting that, taken literally, these phrases tend to oversimplify, they nevertheless represent the resulting worker attitude usually created by several specific factors at hand.

In perhaps the most provocative criticism to date of time study procedures, William A. Gomberg, a leading labor spokesman on the subject, stresses time study's failure to stand the test of scientific validity. Gomberg attributes many of the grievances resulting from its application to this serious deficiency in a system which, from its very inception, has endeavored to be classed as a science rather than merely an art. He exemplifies this failure when he states:

> 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 collating 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 does not deny the usefulness of time studies provided their limitations in accuracy are recognized. Regarding the particular problem of rate setting in industrial wage structures, he feels that time study techniques are at best a type of empirical guide to setting up a range within which collective bargaining over production rates can take place (3). If time study admits inaccuracy in this manner by only establishing a range which may include the correct time standard, this is hardly a scientific achievement.

It could be reasoned then that were we to remove the two most severe faults of time study as proposed by Presgrave: namely, the air of mystery and consequent mistrust in standards derived, and the psychological misapplications too frequently occuring, then the welcome acceptance and support of time study by management, union, and labor would be hindered only by its relative newness and other such hardly insurmountable problems. Leaving for the moment the psychological facet of the problem as a goal to be achieved, through better understanding by time study practitioners of the underlying philosophy of scientific management, it remains for the engineer to seek new methods by which to bridge the existing gap between "time study" and "science". This assumes that this "gap" is the source of the trouble and that the bridging, when and if achieved, will be amenable to normal industrial applications from practical and economical viewpoints. It is entirely possible that either or both of these assumptions are invalid.

Time study's incompatibility with the term "science" is immediately evident even from a cursory examination of its methodology as compared with that of the physical scientist. A science is an organized body of knowledge of facts, phenomena, and laws, verified by exact observation. This body of knowledge normally results from research involving the duality of experiment and theory. Phenomena are first observed randomly, and then mentally formed into a theoretical model from which certain deductions may be drawn. These deductions are then vigorously tested and, depending on the results, the model is rejected and recreated or is accepted as a base from which useful laws of engineering can be derived. Sound reasoning, objectivity, and accuracy are essentials of the entire scientific approach.

Time study, meanwhile, falters severely enough in several phases of its construction to warrant a dissimilar classification. Assumptions as to the nature of the model lying at the foundation of the system are currently being questioned, and early indications are that these basic assumptions themselves are fallacious. If these indications prove correct, then rationalization will easily explain many shortcomings in present-day applications as being mere derivatives of an invalid model, and consequently inaccurate, insecure, and inequitable themselves.

Gomberg justifiably attacks the performance or pace rating technique when he states: "It is at once apparent that nothing has been developed in industrial time study practice that can be considered an objective measure of normality or an objective method for comparing operator performance with any normal standard" (4).

But rational thinking brings to light the often overlooked fact that rating and all other such compensatory techniques exist only in default of sound basic theory, and it is apparent that mathematical adjustment at this "level of error" offers no aid toward relegating the time study into the security of science. Early statistical methods utilized in this type of adjustment have proved unrealistic from a practical standpoint, and Alford and Bangs list five or more prominent time study authorities as all agreeing that the usual system of injecting into results purely subjective measurements is the only workable methodology (5).

In view of the current attacks on these systems by all concerned and the shallow logic inherent in the systems, which feature itself should instigate in the minds of time study engineers a desire for betterment, an alternative theory is certainly worthy of thoughtful examination.

Viewing the underlying structure of time study statistically, as distinguised from a mere adjustment of actual industrial time data, was conceived some time ago. But again Gomberg first provided the real stimulus for research into this area. In the case of deriving production standards from time study, Gomberg asserts that before any meaningful fixed standard can be derived, a constant chance cause system indicative of the presence of a state of statistical control must be in effect in the actual performance of the task under study. This state of statistical control is best illustrated by W. A. Shewhart's famous bowl experiment. His experiment consisted of placing in a bowl a large number of similar chips, each chip being numbered in a carefully planned manner. Random selections are then made one at a time from the bowl in successive samples of size "n". The chips are replaced and thoroughly mixed after each drawing. The results, when tabulated in the form of a frequency distribution indicate that the differences between samples under such conditions are predictable by probability mathematics (6).

Martin Wiberg, in observing that work performance times are quite different from the same work element even when repeatedly performed by the same operator, states that "the science of efficiency and economy in manual work must explain the causes of these variations in performance. It must be known why these movement differences occur, and how they may be utilized and controlled" (7). Subsequently, Wiberg published a graphic presentation of several typical frequency distributions of cycle performance times, or "work-times" by his connotation, and reasoned that the skew, range, and minimum reading of these distributions were related to motivation, aptitude, and training of the worker (8). He recommended comparing distributions as derived in laboratory experiment with his ideal distributions and centering attention on operations producing distributions which differ significantly. However, as Gomberg notes, no quantitative means for comparison purposes are proposed by Wiberg (9).

At the present time, little is known about the pattern, distribution, and stability of rates of output or of daily work habits under various environmental conditions other than resulting gross changes in output. Many have previously assumed a normal distribution of individual work-performance times. Harold O. Davidson refutes the application of the Gaussian distribution to performance times in drawing convincing conclusions from considerable study and experimentations on the subject. He states that "the assumption of normal distribution of relative production rates of industrial workers is operationally invalid. The development of any rule for the statistical definition of a normal worker should be approached with great caution" (10).

The vital phase of performance time data analysis, however, lies not so much in the debate as to the strict normality of performance time distributions, but rather in the question as to the existence of a state of statistical control. Optimum control of work times could present itself in many forms in the category of actual performance curves or accurately controlled performance time ranges within which variation was due to chance alone. Such control would not be dependent upon normality, but instead on a fundamental assumption as stated by Shewart, that:

> ...approximate normality of an observed distribution arising under controlled conditions may be taken as indicating that the cause system is in a state of maximum control. On the other hand, the fact that an observed distribution is not approximately normal is not sufficient evidence that the phenomenon is not in a state of maximum control (11).

Methods of utilizing statistical control charts in the analysis of worker rates of production and in the derivation of work standards are suggested by R. N. Lehrer. In a restatement of the basic premise of statistical quality control as stated by E. L. Grant (12), Lehrer says:

> Measured quantity of production is always subject to a certain amount of variance 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 (13).

The causes of variation outside this stable pattern are labeled "assignable" causes in that they can normally be identified and removed from the system. Common assignable causes of quality variation in machine manufacturing are worn tools, cracked bearings, and so on. These conditions will be reflected in control chart presentations of product measurements, and thus lend themselves to correction.

Lehrer feels that a control chart analysis of the productivity of individual workers "would furnish information about variations in productivity due to individual differences, inconsistency of production standards from job to job, changes in productivity due to physiological and psychological cycles, need for training and additional supervision, etc." (14).

The problem emerges, then, in question form as to the presence of stability in a mass of performance time data when all assignable and hence controllable causes of variation are eliminated. If the presence of a stable system of chance causes is indicated, it is possible that investigation could proceed into the accurate determination of the underlying theoretical model.

As reported in his book entitled Work Measurement, Adam Abruzzi collected production cycle times of workers in the garment industry to investigate the patterns of these times as presented on control charts. Abruzzi found statistical stability present within these times in practically every case. He concluded that such control chart studies would facilitate production rate comparison in determining need for additional operator training, better equipment, and so on. In addition, Abruzzi felt that if stability were evident in these control charts, precise estimates could be made regarding future production rates as well as their limits of variation (15).

In a statistical look at the distributions of operator performance times, W. E. Lind found little evidence of stability in these times and no indication of the presence of a theoretical work curve (16). After gathering considerable performance time data by means of a stop watch on another repetitive type man-controlled operation, Lind found that in an analysis by control chart techniques he was unable to isolate assignable causes of variation in a positive manner. He concluded that common stop watch methods of time data collection are not applicable to this type of study due to the limited breakdown possible of exterior factors included in a recorded cycle time measurement. Lind also concluded that if assignable causes of variation in cycle performance times could be eliminated, a stable distribution or pattern should result. He recommended micromotion study and film analysis as a more effective tool in a study of this nature. Other features of Lind's findings as they directly affect the present study are that the unadjusted performance times tend to form a positively skewed distribution, and that the variation within a period was significantly greater than the variation between periods (17).

Following Lind's recommendation of utilizing micromotion analysis, G. H. Taft made film studies of the same operation and operators as observed by Lind. Taft was interested in the characteristics of cycle time distributions with all normal variables included as compared with the distributions with certain variables removed, these variables having been previously identified by a detailed motion analysis of the work cycles (18).

Taft also found positive skewness in the distributions of the individual operator's cycle times with variables included. These cycle times, however, were modified by Taft to exclude two motion elements considered too unmethodized within and between the operators to exhibit meaningful performance.

Upon eliminating all cycle times including any of the variables as classified, Taft found that his data had been reduced to such an extent that only an overall work shift distribution could be constructed. Nevertheless, the same general characteristics in regard to skewness and overall shape were noted as before in the individual operator distributions (and shift distributions) with variables included. This fact immediately cast doubt upon Lind's contention that removal of assignable causes of variation as identified by micromotion analysis would in effect "stabilize" an otherwise apparently unstable distribution, and Taft concluded that the variables as selected and eliminated within the work cycle did not alter significantly the characteristics of the modified cycle time distribution (19).

However, in drawing conclusions from Taft's results it is important to keep several factors in mind which may be listed as follows without regard to order of importance:

a. Preliminary exclusion from the analysis of cycles containing certain methods changes (20), may have in effect removed several assignable causes of variation which Lind could not have positively identified with stop watch data. The inference would be in such case that Taft's original distributions (variables included) contained a greater degree of stability than Lind's comparable distributions.

b. Taft's classification of variables is necessarily arbitrary, and may include a fewer or greater number of variables than actually were present. A reclassification of variables could produce significantly different results.

c. In excluding from the analysis two motion element times common to all cycles in varying degrees, Taft may have asided determining factors in distribution pattern and stability. However, it does not appear that with the data at hand an accurate evaluation of the influence of these elements can be made (20).

It would appear, then, that Gomberg's suggested control chart procedures still remain theoretically functional in offering the most positive method of attack in a rational analysis of work performance times, the objective being the uncovering of a state of statistical stability or control. Lehrer states that "progressive elimination of assignable causes (of variation) 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" (21).

The advantages of obtaining production rate stability are immediately apparent when the problems of process standardization, cost and production estimation and prediction, and equitable worker compensation are considered. And, as previously mentioned, once such control is attained it is conceivable that scientifically determined performance time standards or standard labor units would be the next step.

Summary

The principal factors in the background of this study emerge as:

a. One reason time study lacks scientific validity is because it is based on an unsound theoretical model for work performance times.

b. This underlying model has been previously thought of as a normal distribution of times, but recent studies tend to refute this.

c. Before the exact nature of this model can be determined, it is necessary to prove the existence of a state of statistical control within these work performance times.

An examination of the literature points to the need of further study of the critical factors influencing this state of statistical control. It appears that certain of these factors should become evident in a control chart analysis of work performance times.

This study, then, will investigate the state of statistical control present in work-time data when some of these assignable causes of variation are removed from the data. Control charts are utilized to exhibit the pattern of variation of these times and consequently enable conclusions to be drawn as to their stability.

CHAPTER II

OBJECTIVE

If insight is to be gained as to the nature of the basic underlying pattern or system of work performance times from which industrial time study samples are drawn, one initial step is establishing the existence of a state of statistical stability or control. Such stability cannot exist if assignable causes of variation are present in the system.

It is the objective of this thesis to identify and, if possible, eliminate certain assignable causes of variation from several representative samples of time study data by utilization of micromotion analysis, on the contention that a state of statistical stability will thereby exist. Control charts will serve to ascertain the presence or absence of this stability.

The problem could be summarized in the form of a null hypothesis as follows: "Removal of assignable causes of variation in cycle performance times as identified by micromotion analysis will not significantly affect the statistical stability of the times as indicated on control charts for means and standard deviations."

This study will attempt to produce evidence of sufficient statistical significance to refute this null hypothesis.

CHAPTER III

PREVIOUS WORK

Overall Project

This thesis is a phase of Study B of a project sponsored by the Georgia Institute of Technology Research Committee under the direction of Doctors R. N. Lehrer and J. J. Moder. As may be surmised from the introduction and objective, the overall purpose of the project is to contribute toward better scientific understanding of the system of work times representing manual repetitive operations.

Previous Work - Study A

The first phase of the project, undertaken by W. E. Lind and reported in his Master's Thesis (22), involved a statistical analysis of work-time data as gathered by means of a stop watch. Ordinary time study procedures were utilized. Information from the results of the first phase which is considered immediately relevant to this study is presented in the Introduction, and it is suggested that direct referral be made to Lind's work for additional facts pertaining generally to the initial method of attack. Several such facts which may purvey a better understanding of the overall problem are:

a. Selection of the operation (a short cycled manually controlled repetitive-type operation performed by female operators).

b. General operational layout and environment.

c. Description of the item produced (a ball point pen).

d. Work method utilized by the operators, with photographs.

Lind's sampling plan generally involved the taking of a continuous sample of 25 work cycles, (i.e., complete assembly of 25 ball point pens), from each operator about once each hour throughout the normal work shift of eight hours. A total of 19 operators covering three shifts were studied in this manner.

For Lind's analysis, each sample of 25 cycles was broken into five subgroups of five cycles each. Control charts as plotted by Lind thus presented points representing subgroups as well as points representing entire samples, with appropriate control limits entered for each.

Previous Work - Study B

G. H. Taft undertook the next phase of the project with a micromotion study of the same operation and operators as observed by Lind. This type analysis was considered especially worthwhile in light of one conclusion drawn by Lind which stated, "Stop watch performance time data do not give sufficient information to separate chance causes from assignable causes of variation" (23). Following Lind's suggestion of using high-speed motion pictures to collect the data, Taft then attempted to determine the effect of certain variables as identified by micromotion analysis on the cycle time distributions.

Significant conclusions from Taft's findings which have bearings upon this study again are presented in the Introduction, and direct referral is suggested to Taft's thesis for additional details of his phase of the project. Some immediately relevant information of this nature which may be found in this reference is as follows:

a. The filming of the operation, performed with a synchronous motor-driven camera taking 2000 frames per minute.

b. Detailed workplace layouts by operators.

c. Elemental breakdown of the operation, and detailed method descriptions by operators.

d. Method of film analysis.

e. Selection of variables.

f. Method of recording data, tabulating frequency distributions, and eliminating variables.

Taft's sampling plan differed somewhat from Lind's in that within each eight hour shift he obtained eight film "shots" of each operator at intervals of approximately one hour's length. Each film shot contained 12 to 15 cycle times representing that number of ball point pens completely assembled. Taft also studied a total of 19 operators, filming all three shifts in one 24-hour period. However, only 15 of this number were the same operators as studied by Lind, transfer and turnover accounting for the difference.

Through a detailed analysis of the film, Taft obtained and recorded on I. B. M. cards the gross cycle times, modified cycle times, the occurrence of variables as classified, and all necessary identifying information (24). This made possible the utilization of an I. B. M. sorting machine in the determination of data required in plotting modified cycle time frequency histograms.

CHAPTER IV

PROCEDURE

General Plan.--The first objective of the analysis as initially planned was to present individual control charts for means and standard deviations of each operator's cycle performance times. The required data for these charts were to be computed on two separate bases as follows:

a. Control charts of all modified cycle times[1] which constituted the data for Study B as made by Taft.

b. Control charts of only the modified times representing performance cycles containing no variables as classified in the present study.

It was assumed that the control charts in (a) above would indicate statistical instability in substantiation of Lind's findings in Study A on the same operators. It followed, then, that the control charts in (b) above should indicate stability if complete and correct identification and isolation of assignable-cause variables had been accomplished.

In the early stages of computation, however, it became evident that a greater degree of stability was present in the time data of Study B than had been anticipated, and a re-examination of Lind's data in Study A appeared to be in order.

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[1] Taft's "modified cycle time" excluded the first and last motion element of each cycle. See above, p.10.

As a result of this apparent confliction in the evidence as to the existence of statistical stability in an operator's usual or habitual cycle times, the original plan was modified to include also a control chart presentation of the data of Study A on the same statistical basis as that of Study B. In this way two evaluations of each operator's exhibited stability would be obtainable. This would render more meaningful any subsequent conclusions as to significant changes brought about by the elimination of the assignable-cause variables.

As an additional aid in determining the the existence of operator stability in the original data of Study B, the plan was modified further to include a presentation of the results of analysis of variance tests made on the same data. This analysis was performed by P. H. Friedman and is described in detail in his Master's Thesis (25).

The overall plan then included three major phases: (1) a control chart analysis of the Study A data to determine stability; (2) a similar analysis of the Study B data, variables included, and a comparison by operator of these charts with those of Study A; (3) a similar analysis of the Study B data, variables excluded, to determine whether a significant change in stability was evident as compared to the previous control charts.

The variables to be excluded from the Study B data were six operator hand-movements or delays which were not considered a necessary part of the normal work cycle. These elements were considered to be assignable causes of variation in the normal performance of the cycle.

The variables selected and eliminated are listed below with the principal reasoning for their elimination:

1. Fumble - A manual handling error not a part of the normal method, and serving no purpose in considerations as to rythm or balance required in the normal performance of the cycle. Fumbles could be caused by momentary distraction of the operator, lack of "job dexterity" or skill as acquired by practice, nervousness while under observation, or other such detectable causes.

2. Drop part - Normally a specific type of fumble or resultant of a fumble. Reasons for eliminating this element are generally the same as above.

3. Get two units, return one - A type of misgrasp of component parts requiring the returning to the stockpile of the extra unit; not a part of the normal method, serves no inherent purpose, and may be directly attributable to the peculiarities of size and shape of the parts at hand.

4. Inspection delay, both hands - Occurs when the operator momentarily performs a visual inspection of the sub-assembled part as a check on correctness of assembly so far. This delay is not required in the normal cycle, since the required motions and the workplace layout are methodized to an extent that the assembly normally proceeds with little if any eye travel at all.

5. Bad part - Normally an inevitable and unpredictable occurrence requiring the discard of the faulty part and replacement. However, bad part occurrence is definitely an assignable cause of variation since theoretical situations exist where all parts are usable, and this philosophy influences the original cycle methodization.

6. Part stuck in staker - An occurrence due to chance improper functioning of the mechanical device or due to variation in part size. However, this is an assignable cause in that the source is readily identifiable and theoretically subject to elimination.

Question may arise as to the justification for the removal of the variables as above in view of their frequent occurrence. Some variables may logically be considered a normal part of the job from the standpoint of wage standards, but in this study the emphasis is on the underlying pattern of stability unaffected by such detectable variation.

The variables listed above include all but four of the original 10 variables which were detected by Taft in his film analysis of the Study B data. The variables not classified herein as assignable causes, with supporting reasons, are as follows:

1. Regrasp - A rapid regrasping of the part in hand to facilitate the assembly of mating parts. Since chance normally determines the position of the operator's original grasp of the part, frequently the part must be regrasped to enable proper assembly. Examination of the film revealed that all operators regrasped occasionally, some even in every assembly cycle. This factor of large frequency of occurrence, together with the obvious impossibility of elimination of the element, suggested that such movements are a normal part of the method.

2. RL, TE, G, A, RL - A combination of therbligs representing a particular type of regrasp. The same reasoning as in (2) above applies.

3. Delay, one hand - Examination of the film indicated that this delay occurred when one hand by chance "got ahead" of the other in the dual-assembly cycle, and consequently paused momentarily mid-cycle to allow the slow hand to catch up. This type delay is unavoidable in two-hand repetitive operations since the operator will unconsciously strive to achieve and maintain a steady and rythmic pace.

4. Inspection delay after staking - Not a part of the modified cycle time.

The procedural steps necessary for the study can be listed as follows:

1. Segregation of the Study B data by operator, and further division into subgroups representing hourly samples of time throughout the work shift. The hourly interval is approximate.

2. Computation of subgroup means and standard deviations, of control chart data, and plotting of the control charts.

3. Segregation of Study A data into subgroups of comparable statistical bias and efficiency to those of Study B.

4. Computation and plotting of Study A data as in (2) above.

5. Tabulation of the results of the analysis of variance tests performed on the data of Study B.

6. Location of and removal from further analysis all cycle times in the Study B data containing one or more of the variables as classified (and noted above).

7. Computation and plotting of these data as in (2) above.

8. Comparison and evaluation of such indications of statistical stability as emerge in the data presentations of Study A, Study B with variables included, the analysis of variance tests, and Study B with the variables excluded.

Data Collection.--The Study B data required for this phase of the project were at hand in the form of information previously punched into I. B. M. cards, supplemented by the original detailed film analysis forms. Descriptions and illustrations of these cards and forms are given in Taft's thesis (26). The information derived from them which was of primary concern to this study is as follows:

a. Shift number
b. Operator number

c. Film shot number and time of day taken, a "shot" being one hourly subgroup of a maximum of 15 cycles.

d. Modified cycle times.

c. The occurrence of variables as classified by Taft.

To simplify a portion of the necessary control chart calculations and at the same time present a convenient summary of all information contained on the machine cards, an I. B. M. card sorter and tabulator were employed to present in printed form all card information grouped by shots, and to perform and record several initial steps in the calculations of means and standard deviations.

The Study A data required were obtained directly from Lind's thesis or from his original time study observation sheets and the project log. Lind's "period" (27) made up of five subgroups of 25 observations per subgroup was selected as the statistical measure most comparable to Taft's "shot" consisting of from 12 to 15 cycle observations. The basis for this selection was the fact that, first, Lind's period was actually 25 successive cycles with no break between cycles, and hence comparable to Taft's shot, and, second, Lind's periods were taken at approximately the same intervals throughout the work day as were Taft's shots.

It should be mentioned here that Taft eliminated a considerable portion of his original data from the complete analysis for such reasons as (1) abandonment of the normal method, (2) handling or positioning the stock of parts, and

(3) variation in certain motion elements. In addition, a large amount of data from the first shift observations was eliminated from any analysis because the camera motor used during the filming did not function properly during the entire shift.

Operator Designation.--To facilitate comparison between operators in Study A, Study B, and the present study, each individual operator was given a letter designation. Table 1, page 29, gives the designations given operators in the previous theses with the present letter designation corresponding to the same individual.

Definition of Terms.--In addition to the operator designation, the following definitions will apply to terms appearing in this thesis:

Cycle - one observation, or the dual assembly of a pair of ball point pens.

Shot - the largest homogeneous subgroup of cycles, varying in number up to 14 in Study B, but essentially constant at 25 cycles in Study A.

X - one cycle time.

$\bar{X}$ - mean of cycle times in one shot.

$\bar{\bar{X}}$ - mean of shot means, or operator's mean cycle time. This value is a weighted mean in the case of varying sample sizes.

s - standard deviation of cycle times within one shot.

σ - the unbiased estimate of the universe standard deviation (also a weighted value in the case of varying sample sizes.

n - number of cycles per shot.

N - number of shots per operator.

N_n - total number of cycles per operator.

$UCL_{\bar{x}}$ - upper control limit of x values.

$LCL_{\bar{x}}$ - lower control limit of x values.

UCL_s - upper control limit of s values.

LCL_s - lower control limit of s values.

Unless otherwise noted, these terms apply both to presentations of data of Study A and Study B, with appropriate additional designation. All other terms used are standard statistical terms unless noted, and definitions can be secured from any statistics text.

CHAPTER V

ANALYSIS

Study B Data - Variables Included

The data for each operator was divided into 8 shots, each containing a maximum of 14 cycles. The shot mean times was computed and designated $\bar{x}$.

The operator's mean cycle time was computed using the formula for weighted means,

$$\bar{\bar{X}} = \frac{x_1 n_1 + x_2 n_2 + \cdots \; x_k n_k}{n_1 + n_2 + \cdots n_k},$$

where n denotes number of cycles per shot.

The standard deviation of cycle times within one shot was computed using

$$s = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n-1}},$$

where x denotes the cycle times in the shot.

A pooled estimate of the universe standard deviation was obtained using the weighted variance formula,

$$\sigma^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2 + \cdots (n_k-1)s_k^2}{n_1 + n_2 + \cdots n_k - k}$$

For control chart presentation, σ, the unbiased estimate of the universe standard deviation obtained from above, was used as the center line on the chart for shot standard deviations.

As an estimate of the standard deviation of the distribution of s for the shots the approximation

$$\sigma_s = \frac{\sigma}{\sqrt{2n}} \left[2(n-1) - 2nc_2^2 \right]^{\frac{1}{2}}$$

was used, where c_2 is the ratio of the average of standard deviations of samples of a given size to the standard deviation of the parent universe. The formula for the c_2 factor and tables of values can be found in most statistics texts (28).

In obtaining limits of $3\sigma_s$ for the control chart for standard deviations, it can be shown that a modification of Grant's (29) B, and B_2 factors will present two new factors (herein called B_5 and B_6) which will equal the constant portion of the expression immediately above. The modification reduces to

$$B_5 = B_2 + 1 - c_2$$

and

$$B_6 = B_1 + c_2$$

These factors can now be used in computing 3-sigma control limits for the control chart for standard deviations as follows:

$$UCL_s = B_5\sigma$$

$$LCL_s = B_6\sigma$$

Control limits for the $\bar{x}$ chart were computed about a center line of $\bar{\bar{x}}$ using the A fa ctor as given by Grant (30) and the appropriate value of σ:

$$UCL_{\bar{X}} = \bar{\bar{X}} + A\sigma$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A\sigma$$

Study B Data - Variables Excluded

Computations were performed in the same manner as outlined above, and control charts of similar construction were prepared. However, in these computations all cycle times which contained any of the 6 variables classified as assignable causes were eliminated.

Study A Data

Computations were performed in the same manner as for the data of Study B except that sample or shot size was generally constant at 25. In the three subgroups where n was 15, appropriate weighting of statistics was performed.

One set of control limits served each particular control chart due to the essentially uniform subgroup size.

Table 1. Comparative Operator Designation--All Studies

Operator No. Study A (Lind)	Shift No.	Operator No. Study B (Taft)	Operator Desig. Present Study
1	1	..	A
2	1	4	B
3	1	..	C
4	1	1	D
5	1	2	E
6	1	5	F
7	1	7	G
8	2	8	H
9	2	13	J
10	2	9	K
11	2	..	L
12	2	10	M
13	3	19	N
14	3	16	P
15	3	18	Q
16	3	17	R
17	3	14	S
18	3	15	T
19	3	..	U
..	1	3	V
..	1	6	W
..	2	11	X
..	2	12	Z

Table 2. Operator Personal and Productiinn Data

Oper. No.	Experience at time of study A. (months)	Experience at time of study B. (months)	Production, in units per hour Study B
A	-	-	-
B	5	10	500
C	-	-	-
D	1	6	485
E	5	10	527
F	5	10	449
G	6	5	526
H	3	6	421
J	7	10	430
K	7	10	441
L	-	-	-
M	8	10	516
N	3	5	479
P	6	8	578
Q	8	10	578
R	8	10	578
S	8	10	448
T	5	7	557
U	-	-	-
V	-	9	528
W	-	1/2	306
X	-	6	491

Table 2 Operator Personal and Production Data (Continued)

Oper. No.	Experience at time of study A. (months)	Experience at time of study B. (months)	Production, in units per hour Study B
Z	-	8	418

CHAPTER VI

RESULTS

Interpretation

In analyqing the control charts constructed it was necessary to consider several factors in addition to those concerned with the overall objective discussed previously. The major points of concern were:

(1) The control charts in Study A were constructed from direct stop watch times which were gross cycle times. The Study B time data was composed of modified cycle times, or two motion elements less than the gross cycle time. Consequently, no quantitative comparison of mean or standard deviation values could be made between Studies A and B.

(2) The sample sizes in Study B were of a relatively small size ($n \leqq 14$). This fact tended to restrict most inferences as to the existence of characteristic work waves.

(3) The injection of a certain amount of subjective judgment is necessary in the analysis of control charts. This is especially true when the data, as in this case, are derived from human beings as opposed to the usual machine control chart.

Tabulation of Results

Table 3 is a tabulation of all significant observations made on the control charts. In Table 3, and also in the detailed results section following, the two phases of analysis with the Study B data are referred to for convenience as Study B-1 (meaning variables included) and Study B-2 (meaning variables excluded).

Table 3. Summary of Results from Control Chart Analysis

Oper. No.	Figure No.	Study No.	$\bar{x}$'s Stable: Control Chart	$\bar{x}$'s Stable: Anal. of Variance	s's Stable: Control Chart	Changes from Study B-1 to Study B-2 & Remarks
H	1	A	No	-	Ques	No significant change
		B-1	Yes	No	Yes	
		B-2	Yes	-	Yes	
K	2	A	Yes	-	Yes	Run and trend in s chart eliminated no significant change in $\bar{x}$ chart.
		B-1	No	No	Yes	
		B-2	No	-	Yes	Two $\bar{x}$ points out of control, cause undetermined.
M	3	A	No	-	No	Limits on s chart refined causing new point to fall outside lower control limit.
		B-1	Yes	Yes	No	
		B-2	Yes	-	No	No significant change in stability of either chart.
X	4	A	-	-	-	A significant gain of stability evidenced on both $\bar{x}$ and s charts.
		B-1	No	No	No	
		B-2	Yes	-	-	

Table 3. Summary of Results from Control Chart Analysis
(Continued)

Oper. No.	Figure No.	Study No.	$\bar{X}$'s Stable: Control Chart	$\bar{X}$'s Stable: Anal. of Variance	s's Stable: Control Chart	Changes from Study B-1 to Study B-2 & Remarks
Z	5	A	-	-	-	Apparent gain of stability, but not statistically significant on control charts.
		B-1	Yes	No	Yes	
		B-2	Yes	-	Yes	No affect on run or trend' present in B-1

Table 3. Summary of Results from Control Chart Analysis (Continued)

Oper. No.	Figure No.	Study No.	$\bar{x}$'s Stable: Control Chart	$\bar{x}$'s Stable: Anal. of Variance	s's Stable: Control Chart	Changes from Study B-1 to Study B-2 & Remarks
J	6	A	Yes	-	No	Significant gain of stability of s chart. Slight increasing trend on $\bar{x}$ chart reduced. Run of s points in B-1 eliminated.
		B-1	Yes	Yes	No	
		B-2	Yes	-	Yes	
S	7	A	Yes	-	No	Significant gain of stability on $\bar{x}$ chart.
		B-1	No	No	Yes	
		B-2	Yes	-	Yes	
T	8	A	Yes	-	Yes	No significant change in $\bar{x}$ or s charts; indicated $\bar{x}$ decreasing trend more distinctly.
		B-1	Yes	Yes	Yes	
		B-2	Yes	-	Yes	
P	9	A	Yes	-	Yes	85% of data eliminated with removal of variable; resulting $\bar{x}$ and s charts meaningless.
		B-1	Yes	Yes	Yes	
		B-2	Yes	-	Yes	

Table 3. Summary of Results from Control Chart Analysis
(Continued)

Oper. No.	Figure No.	Study No.	$\bar{x}$'s Stable: Control Chart	$\bar{x}$'s Stable: Anal. of Variance	s's Stable: Control Chart	Changes from Study B-1 to Study B-2 & Remarks
R	10	A	Yes	-	Yes	Decreasing $\bar{x}$ trend indicated more distinctly.
		B-1	Yes	Yes	Yes	
		B-2	Yes	-	Yes	

Table 3. Summary of Results from Control Chart Analysis (Continued)

Oper. No.	Figure No.	Study No.	$\bar{x}$'s Stable: Control Chart	$\bar{x}$'s Stable: Anal. of Variance	s's Stable: Control Chart	Changes from Study B-1 to Study B-2 & Remarks
Q	11	A	Yes	-	Yes	Decreasing $\bar{x}$ trend indicated more distinctly.
		B-1	Yes	Yes	Yes	
		B-2	Yes	-	Yes	
N	12	A	Yes	-	Yes	Limits on $\bar{x}$ chart refined causing new point to fall outside control. Trend in s appears.
		B-1	Yes	No	Yes	
		B-2	No	-	Quest.	

Note: The data on Operators W, G, D, E, V, B, and F was insufficient to plot meaningful control charts for analysis. Operators A, L, C, and U were not covered in this study.

Details of Results

This section is a presentation by operator of the specific results as observed on the control charts. References are made to the tables and figures concerned. As mentioned previously, Study B-1 and Study B-2 refer to the phases of analysis on the Study B data with variables included and variables excluded, respectively. See Table 4 for all Study A control chart data and Table 5 for all references to the analysis of variance results.

Operator H - (See Figure 1 and Table 6)

Study A.--The $\bar{x}$ chart shows four points out of control and a definite trend for means to decrease during the shift.

The s chart shows a slight trend for variance to decrease during the shift, although the significance of the trend regarding stability is questionable.

Study B-1.--The $\bar{x}$ chart shows no points out of control, although two points are near the control limits.

The s chart shows random variation with no trends nor points out of control.

The analysis of variance indicates a probability of .04 that the difference in means is due to chance; hence the hypothesis of equal means among the shots is rejected.

Comment.--With the s values apparently stable, the analysis of variance is more sensitive to the widely dispersed means and thus tends to refute the assumption of stability.

Study B-2.--A total of 21 cycles were removed from the original

66, leaving 45. The $\bar{x}$ chart shows no points out of control and only a slight change in pattern.

The s chart shows 6 of the 8 total points below the center line, but no points out of control.

Comment.--The refining of the control limits has increased considerably the doubt as to the stability of the 3:30 P.M. $\bar{x}$ shot.

Discussion.--The decreasing trend of $\bar{x}$ and s in Study A, which suggests that as the oerator worked faster her motion cycle became more standardized, is not evident in any charts of Study B. But learning progress is apparent from Study A to Study B, evidenced by the large decrease in the operator's mean cycle time and the stability of both $\bar{x}$ and s.

Doubt as to the stability of the 3:30 P. M. x shot, Study B, was increased when the variables were excluded. Examination of the film analysis data showed two "regrasps" each in the two highest time cycles includes in the remaining number of cycles in this shot. However, tow and more regrasps also occurred in other cycles with considerably lower times. No other cause for these high values was evident.

There is a significant gain in stability from Study A to Study B, but this conclusion must be weighed in view of the intervening time lapse. There is no significant change in stability in the two phases of Study B.

Operator K - (See Figure 2 and Table 7)

Study A.--The $\bar{x}$ chart shows no points out of control, although the limits are quite wide due to a randomly distributed but widely dispersed s, as indicated on the s chart. No trends or runs are evident in either chart. Stability is indicated.

Study B-1.--Two points are outside the upper control limits on the $\bar{x}$ chart, namely the shots taken at the beginning and end of the shift. No trend is evident.

The s chart has no points out of control, but indicates a definite trend for variability to decrease throughout the shift. A run of six points below the center line is present, the probability being only .031 that this is a chance occurrence. The high s value at 3:30 P. M. corresponds to the first $\bar{x}$ point out of control, but the 1:45 P. M. $\bar{x}$ point has a value of s slightly below the center line, thus suggesting no correlation.

Study B-2.--A total of 18 cycles were removed from the original 79, leaving 61. The $\bar{x}$ chart shows the same two points out of control, their values not having been appreciably reduced by the elimination of 2 and 1 cycles respectively. In addition, the 5:20 P. M. shot is now doubtful. No positive change in pattern is present.

The s chart shows that the 3:40 P. M. value is still inside the upper control limit, but only slightly so. The previous six point run has been broken up, and the decreasing trend is less pronounced.

Comment.--It appears likely that were the s value at 3:40 P.M. eliminated, the center line on the s chart would be lowered and a random pattern of s would result.

Discussion.--No significant change in stability is evident on the $\bar{x}$ chart with variables excluded. Examination of the film analysis data revealed no apparent cause for the out of control points remaining.

Although the magnitude of the variance remained essentially unchanged, indications of stability on the s chart are significantly increased if the first value is attributed to an undetected assignable cause.

Operator M - (See Figure 3 and Table 8)

Study A.--The $\bar{x}$ chart shows two points out of control and a definite trend for mean times to decrease during the shift (except in the case of the last two points which indicate a final slowdown and subsequent mean time increase).

The s chart corresponds very well to the $\bar{x}$ chart in that variance as shown tends to decrease slightly during the shift, again with the exception of the last two points which fall above the upper control limit.

Comment.--The similarity stability-wise of the final two $\bar{x}$ and s values suggests slowdown as caused by intentional introduction of delays or other assignable causes in some cycles, which increases the shot mean and variability.

Study B-1.--The $\bar{x}$ chart shows no points out of control, no runs, and no trends. The 4:35 P. M. shot approaches the lower control limit, however.

The s chart shows one point out of control and one point approaching the lower control limit.

Comment.--The analysis of variance agrees with the $\bar{x}$ control chart by not refuting the assumption of stability in spite of the lack of control in variance. This shows that moderate violations of one of the basic assumptions in the analysis of variance test, namely, the assumption of equal variance, will not affect the resulting indication of $\bar{x}$ stability.

Study B-2.--A total of 15 cycles were removed from the original 71, leaving 56. No significant change in stability is indicated on the $\bar{x}$, although the 4:35 P. M. shot is more removed from the lower control limit due to a widening of these limits.

The s chart now shows the 7:45 P. M. shot out of control in addition to the 4:35 P. M. shot as before. Otherwise, there is no significant change in the chart pattern.

Comment.--The lowering of the center line on the $\bar{x}$ chart, combined with the lowering of the 3:45 P. M. and 10:50 P.M. shots, suggests a purely subjective interpretation of the greater stability in the chart pattern. Refining the limits on the s chart confirms the original suspicion of lack of control in the 7:45 P. M. shot.

Discussion.--The downward trend of $\bar{x}$ and s in Study A is not present in any charts of Study B. Stability is gained from Study A to Study B as regards mean times only, but no significant change in stability occurs from the first to second phase of Study B. Examination of the film analysis data reveals no apparent correlation between regrasps or delays and the out of control s values. Removal of variables as performed on the Study B data refined the time control limits, offering a more positive identification of unstable shots.

Operator X - (See Figure 4 and Table 9)

Study B-1.--The $\bar{\bar{x}}$ chart shows one point out of control, but otherwise no runs or trends.

The s chart shows one value out of control which corresponds to the $\bar{\bar{x}}$ value above. No runs or trends are indicated otherwise.

The analysis of variance indicates a probability of less tha .01 that the difference in means is due to chance; hence, the hypothesis of equal means among the shots is rejected.

Study B-2.--Only 7 cycles were removed from the original 77, leaving 70. Four of the 7 cycles removed were taken from the one out of control shot. The $\bar{\bar{x}}$ chart shows a significant change in stability in that all points are now in control, the center line is lowered, and there are no indications of nonrandomness in the resulting pattern.

The s chart center line has also bee lowered and only chance variation is indicated in the pattern.

Comment.--The significant gain of stability in both charts is largely due to the lowering of the $\bar{\bar{x}}$ and s values of the 11:00 P. M. shot. Therefore, inferential conclusions must be tempered in view of the small number of measurements involved, particularly in the final value.

Discussion.--The removal of variables has significantly affected the stability of the data for this operator in that the $\bar{\bar{x}}$ and s charts now show no points on either control chart as out of control and no evidence of runs or trends.

Operator Z - (See Figure 5 and Table 10)

Study B-1.--The $\bar{x}$ chart shows no points out of control, but the 3:55 P. M. shot appraoches the upper control limit. A slight trend for mean times to decrease during the shift is in evidence. A run of five points below the center line is observed, the probability being .062 that this is a chance occurrence.

The s chart has no points out of control but both the 3:55 P. M. shot and the 9:35 P. M. shot approach the control limits. Again a slight trend toward decreasing variance during the shift is in evidence.

Commnt.--The analysis of variance again reacts to a high $\bar{x}$ value with s values apparently stable.

Study B-2.--A total of 7 cycles were eliminated from the original 65, leaving 58. No points are out of control on the $\bar{x}$ chart, the 3:55 P. M. shot value having been reduced. The trend for mean times to decrease during the shift is still slightly evident but less pronounced. The 5 point run below the center line is still observed.

The s chart indicates stability of variance with no points out of control, no runs, and no trends.

Comment.--Although conclusive proof is not evidenced on the $\bar{x}$ chart, it appears that the chart with variables removed has gained significantly as concerns randomness of pattern.

Discussion.--Although the trend on the $\bar{x}$ chart has not been entirely removed, it is apparent that the elimination of the 3:55 P. M. shot would lower the center line and produce a random pattern. Examination of the film analysis data concerning this shot reveals one significantly high cytle time containing within itself four regrasps and one one-hand delay.

The s chart with variables excluded gives more convincing evidence of stability.

Operator J - (See Figure 6 and Table 11)

Study A.--The $\bar{x}$ chart shows no points out of control, but a trend of increasing mean cycle times during the shift is in evidence.

The s chart shows two points out of control, another closely approaching the lower control limit, and a distinct trend for variability to increase during the shift. Indications of instability are definite.

Study B-1.--The $\bar{x}$ chart shows no points out of control, but a slight trend of increasing mean times is apparent.

The s chart shows one point out of control and one additional point approaching the lower control limit. Seven of the eight shots fall below the center line. A run of six points below the center line is present.

Comment.--In view of the slight $\bar{x}$ trend and the non-randomness of the s chart, the general conclusion would be that instability exists. However, as supported by the analysis of variance, the evidence as presented by the charts is inconclusive.

Study B-2.--A total of 9 cycles were removed from the original 82, leaving 73. The $\bar{x}$ chart shows no points out of control, and the slight trend of increasing times is no longer apparent.

The s chart now shows no points out of control and gives a definite indication of stability.

<u>Discussion</u>.--No definite conclusions can be drawn as to whether the $\bar{x}$ values are significantly more stable with variables excluded. However, their was a significant gain of stability in the s chart, the limination of variables from the 9:40 P. M. (out of control) shot being the factor responsible.

<u>Operator S</u>-(See Figure 7 and Table 12)

<u>Study A</u>.--The $\bar{x}$ chart shows no points out of control and no trends or runs present.

The s chart shows one point out of control, no runs, but a slight increasing trend.

<u>Study B-1</u>.--The $\bar{x}$ chart shows one point out of control. With a total of only five shots in the data, additional interpretation is not justified.

The s chart shows no points out of control.

The analysis of variance indicates a probability of .01 that the difference in means is due to chance; hence the hypothesis of equal means among shots is rejected.

<u>Study-B-2</u>.--A total of 20 cycles were removed from the original 42, leaving 22. Thus removed were all cycles constituting the out of control $\bar{x}$ shot at 3:30 P. M. Hence the $\bar{x}$ chart now has no points out of control and with the limited number of shots at hand gives no indication of instability.

The s chart shows no significant change in pattern or stability.

<u>Discussion</u>.--Although the amount of data considered was small,

a significant gain of stability was exhibited in the $\bar{x}$ chart with the removal of the variables in that only the out of control point was affected appreciably, and this point was eliminated entirely.

Both phases of Study B showed a significant gain in stability on the s chart as compared with that of Study A.

Operator T - (See Figure 8 and Table 13)

Study A.--The $\bar{x}$ chart shows no points out of control but indicates a slight trend of decreasing mean cycle times.

The s chart shows no points out of control, but also indicates a definite trend of decreasing variance through the shift.

Study B-1.--The $\bar{x}$ chart shows no points out of control, but has some indication present of a decreasing type trend.

The s chart shows no points out of control and no indications of instability.

The analysis of variance indicates a probability of .20 that the difference in means is due to chance; hence the hypothesis of equal means among the shots is not rejected.

Study B-2.--A total of 12 cycles were eliminated from the original 81, leaving 69. The $\bar{x}$ chart shows no points out of control, but a trend of decreasing mean cycle times is clearly in evidence.

The s chart shows no significant change in pattern or stability.

Discussion.--The trend of decreasing $\bar{x}$ values which was suggested in Study A was rendered questionable in Study B with variables indicates a trend of decreasing mean times throughout the shift.

The s chart shows no points out of control and no pattern or trend indicating instability.

The analysis of variance indicates a probability of .20 that the difference in means is due to chance; hence the hypothesis of equal means among shots is not rejected.

Study B-2.--A total of 32 cycles were removed from the original 88, leaving 56. The resulting $\bar{x}$ chart is not significantly different from that with variables included, although the decreasing-type trend is more clearly indicated.

The s chart shows no significant charge in pattern or stability.

Discussion.--The decreasing-type trend in Study A is not indicated in either phase of Study B.

Again the removal of certain assignable-cause variables tended to more clearly define the existence of a trend in the $\bar{x}$ chart data.

Operator Q - (See Figure 11 and Table 16)

Study A.--Both the $\bar{x}$ and s charts show no points out of control and no other indications of instability.

Study B-1.--The $\bar{x}$ chart shows no points out of control, but indicates a trend of decreasing mean times during the shift.

The s chart shows no points out of control and no other indications of instability.

The analysis of variance indicates a probability of .20 that the difference in means is due to chance; hence, the hypomediate supposition would be that instability was present but not indicated on the control charts due to a compensating effect. This effect would be necessary since the variables as classified are inevitably time consuming. That this compensating system is in effect is substantiated by the fact that the operator's mean cycle time is lower than that of 14 of the remaining 18 operators; the operator's production rate is not exceeded by any of the operators.

Therefore, one of two hypotheses appears tenable, the first being that the operator is working at a constant pace considerably faster than normal due to presently unknown cause factors. The operator may customarily work at this pace and the assignable-cause variables may be a direct resultant of excessive haste. The second hypothesis is that the operator inadvertently but frequently commits some manual errors herein classed as variables and subsequently increases the work pace to compensate.

In any event, the $\bar{x}$ chart presentation with variables removed would indicate need for such investigation.

Operator R - (See Figure 10 and Table 15)

Study A.--The $\bar{x}$ chart shows no points out of control and no other indications of instability.

The s chart shows no points out of control, but does indicate a slight trend for variance to decrease during the shift.

Study B-1.--The $\bar{x}$ chart shows no points out of control, but includes, but emerged very clearly when the variables were removed in the second phase of Study B. Thus in this case, certain assignable-cause variables concealed a definite trend existing in the data.

The decreasing s trend in Study A dissipated in both phases of Study B, but no significant change in pattern or stability was evident between these Study B phases themselves.

Operator P - (See Figure 9 and Table 14)

Study A.--The $\bar{x}$ chart shows no points out of control. However, mean cycle times are observed to fall high at the start of the shift, decrease during the period and rise again towards the end of the shift.

The s chart shows no points out of control, but the points follow generally the pattern of the corresponding $\bar{x}$ values.

Study B-1.--The $\bar{x}$ chart shows no points out of control and no trends or runs indicative of instability.

The s chart shows no points out of control, but 6 of the eight values fall below the center line. In addition, a run of five points below the center line is observed, the probability being .06 that this is a chance occurrence.

The analysis of variance indicates a probability of .12 that the difference in means is due to chance; hence the hypothesis of equal means among the shots is not rejected.

Comment.--Learning progress is indicated by the large decrease of operator mean cycle time from Study A to Study B.

Discussion.--With the elimination of 85% of the original data as cycle times affected by assignable-cause variables, the imthesis of the equal means among the shots is not rejected.

Study B-2.--A total of 18 cycles were removed from the original 92, leaving 74. The resulting $\bar{x}$ chart is not significantly different from that with variables included, although again the decreasing-type trend is more clearly indicated.

The s chart shows no significant change in pattern or stability.

Discussion.--No significant conclusions are justified except that again the $\bar{x}$ trend became more clearly defined with the removal of variables.

Operator N - (See Figure 12 and Table 17)

Study A.--Both the $\bar{x}$ and s charts show no points out of control, no runs, and no trends.

Study B-1.--The $\bar{x}$ chart shows no points out of control but one value is observed approaching the lower control limit.

The s chart explains the dispersion of the $\bar{x}$ values but shows no points out of control.

Comment.--Although not in line with the above, in view of the wide dispersion of $\bar{x}$ and s values, and the points approaching control limits, the subjective inference would be that of instability being present.

The analysis of variance indicates a probability of .04 that the difference in means is due to chance; hence the hypothesis of equal means among the shots is rejected.

Study B-2.--A total of 26 cycles were eliminated from the original 69, leaving 43. The $\bar{x}$ chart shows the $\bar{x}$ value carrying doubt previously as actually being out of control. Other values are changed significantly in magnitude but with no apparent consistency as to a decreas or increase.

The pattern of the s chart has changed significantly with an increasing-type trend of variance now exhibited. In addition, a 6 point run below the center line (probability of chance occurrence .031) is now evident.

Discussion.--The "extreme" stability indicated in Study A is refuted in the data of both phases of Study B, although again such comparisons must be weighed in light of time lapse intervening. Nevertheless, the deviation-absorbing nature of stop watch time study as compared to a film study is clearly emphasized here.

No significant change occurred in the $\bar{x}$ for Study B-1 (variables removed) with the exception of the now-positive classification of the 3:55 P. M. shot as out of control. Examination of the film analysis data failed to give any insight as to the cause of this value's instability in the lower range.

Apparently a trend existed in the s chart data which was concealed until the removal of certain assignable-cause variables.

Operator W - (See Figure 13 and Table 18)

Study B.--The $\bar{x}$ chart showed no points out of control, but the sample sizes are so small as to render a conclusion of stability unreliable.

The s chart shows one point out of control and two others approaching the control limits.

The analysis of variance indicates a probability of less than .01 that the difference in means is due to chance; hence, the hypothesis of equal means among the shots is rejected.

Study B-2.--No significant change is evident on the $\bar{x}$ chart with the removal of 3 cycles from the original 22, leaving 19.

The s chart verifies two values as being out of control.

Discussion.--At the time of the study, this operator had less than one month's experience on the job, and consequently does not provide representative nor meaninful data on this operation. Inspection of the film analysis data reveals a greatly excessive number of delays, regrasps, and other manual errors.

Operator G - (See Figure 14 and Table 19)

Study A.--The $\bar{x}$ and s charts each show the 12:55 P. M. shot as being out of control.

Study B-1.--The $\bar{x}$ chart shows the 2:55 P. M. mean cycle time out of control.

The s chart shows an increasing-type trend during the latter part of the shift.

The analysis of variance indicates a probability of less than .01 that the difference in means is due to chance; hence, the hypothesis of equal means among the shots is rejected.

Study B-2.--A table of 17 cycles were removed from the original 41, leaving 34. No significant change is evidenced in the $\bar{x}$ chart.

The s chart now shows one point out of control, this value corresponding to the one $\bar{x}$ point outside the control limits.

Discussion.--It is unrealistic to draw inferences from so little data. However, the film analysis data concerning the 2:55 P. M. shot was examined for possible causes of this high value. The data revealed the presence of four or five regrasps plus one or two delays in essentially all cycles.

Operators D, E, V, B, and F

Study A and Study B Control Charts.--For reasons previously mentioned, the original data for these operators was reduced to the following quantities in Study B:

Operator D.--Four shots, N_n is 23

Operator E.--Four shots, N_n is 42

Operator V.--Three shots, N_n is 33

Operator B.--One shot, N_n is 8

Operator F.--Two shots, N_n is 8

It is apparent that any inferential conclusions drawn from these data would be wholly unreliable, hence such analysis was omitted.

See Figures 15, 16, 17,18, and 19, and Tables 20, 21, 22, 23, and 24.

Operators A, L, C, and U

Study A Control Charts.--For reasons previously mentioned, data on these operators was not available in Study B. However, for completeness of the overall situation, control charts for $\bar{x}$ and s identical in construction with those of other operators are presented herein.

Charts for means and ranges computed from these same data appear, of course, in Lind's thesis (31), and his analysis of the charts is generally applicable to the $\bar{x}$ and s charts herein and will not be repeated.

See Figures 20, 21, 22, and 23, and Table 4.

Summary

In the final analysis, there was sufficient data to cover only 12 operators, with data representing four shots or less for an operator being considered insufficient.

In control charts for means and standard deviations, the following results were noted when the cycles containing variables as classified were eliminated from the present data:

(1) Control chart data for three operators' means or standard deviations evidenced a significant gain of stability, in that points on these charts which were originally out of control were reduced so as to place them within the control limits.

(2) Trends of decreasing mean cycle times during the shift were made more distinct or pronounced in the case of three operators' data.

(3) Control limits on one operator's $\bar{x}$ chart and on one operator's s chart were refined and subsequently new points fell outside the limits.

(4) A previously unapparent trend of increasing variance was revealed in the case of one operator.

(5) One operator's data was reduced 85 per cent, rendering subsequent control charts meaningless.

(6) A six-point run and decreasing trend of s values was found in the case of one operator.

(7) Although statistically insignificant from the control chart standpoint, one operator's $\bar{x}$ and s charts showed an apparent gain in stability in that the patterns of values were more randomly distributed.

(8) No significant or apparent change of stability regarding points out of control pattern, trend, or run was found in the case of one operator.

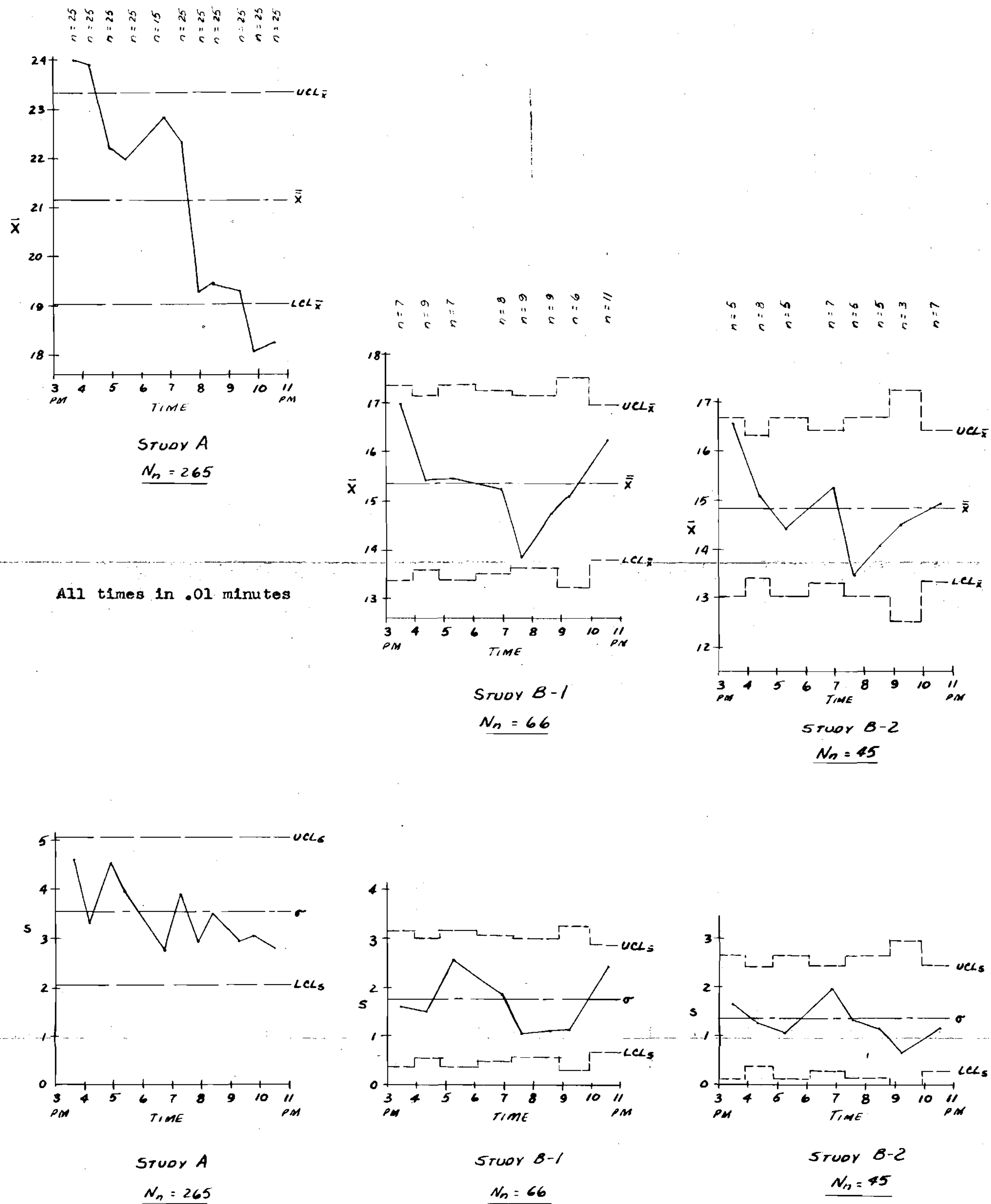


Figure 1. Control Charts for Means and Standard Deviations--Operator H

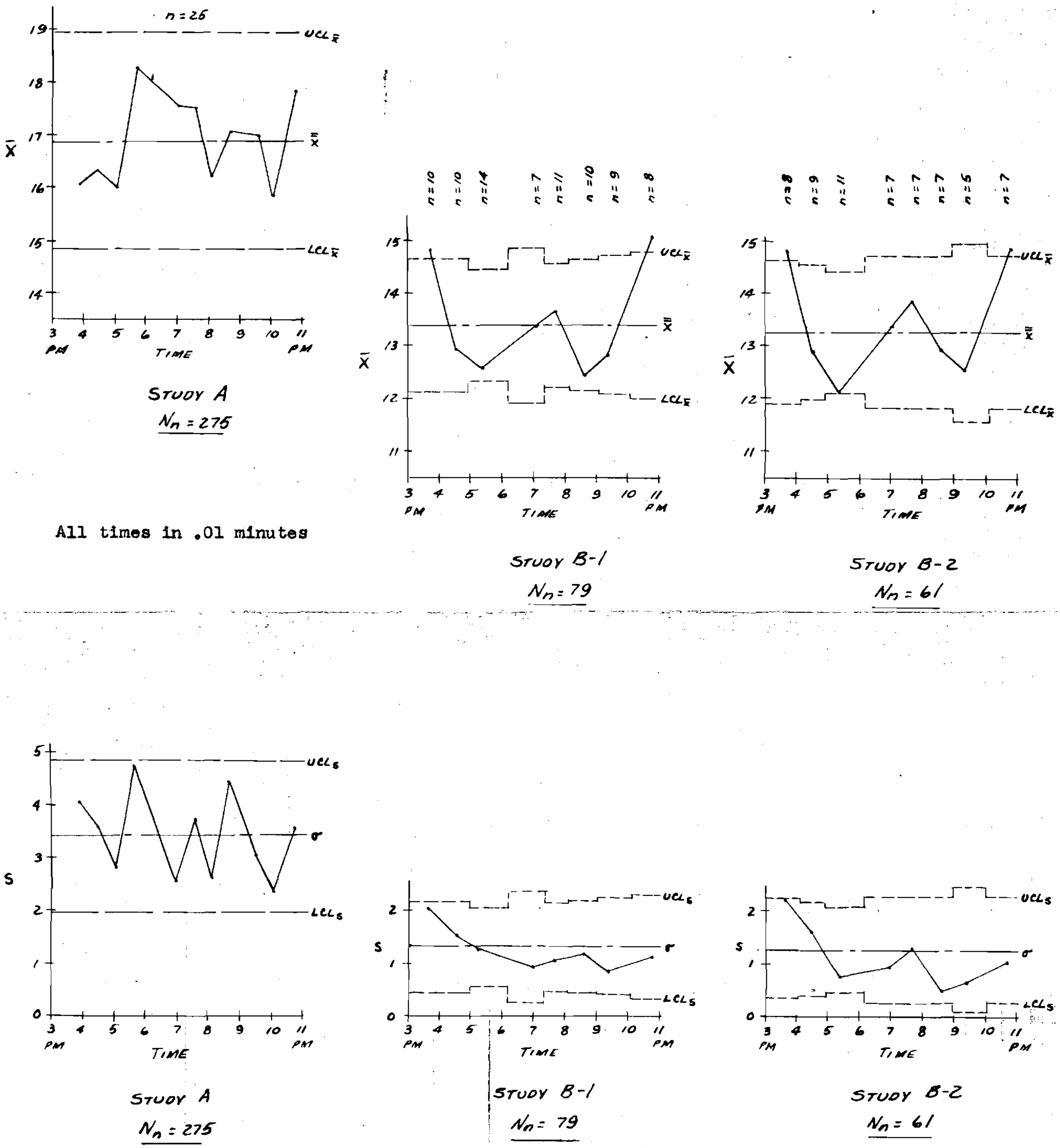


Figure 2. Control Charts for Means and Standard Deviations--Operator K

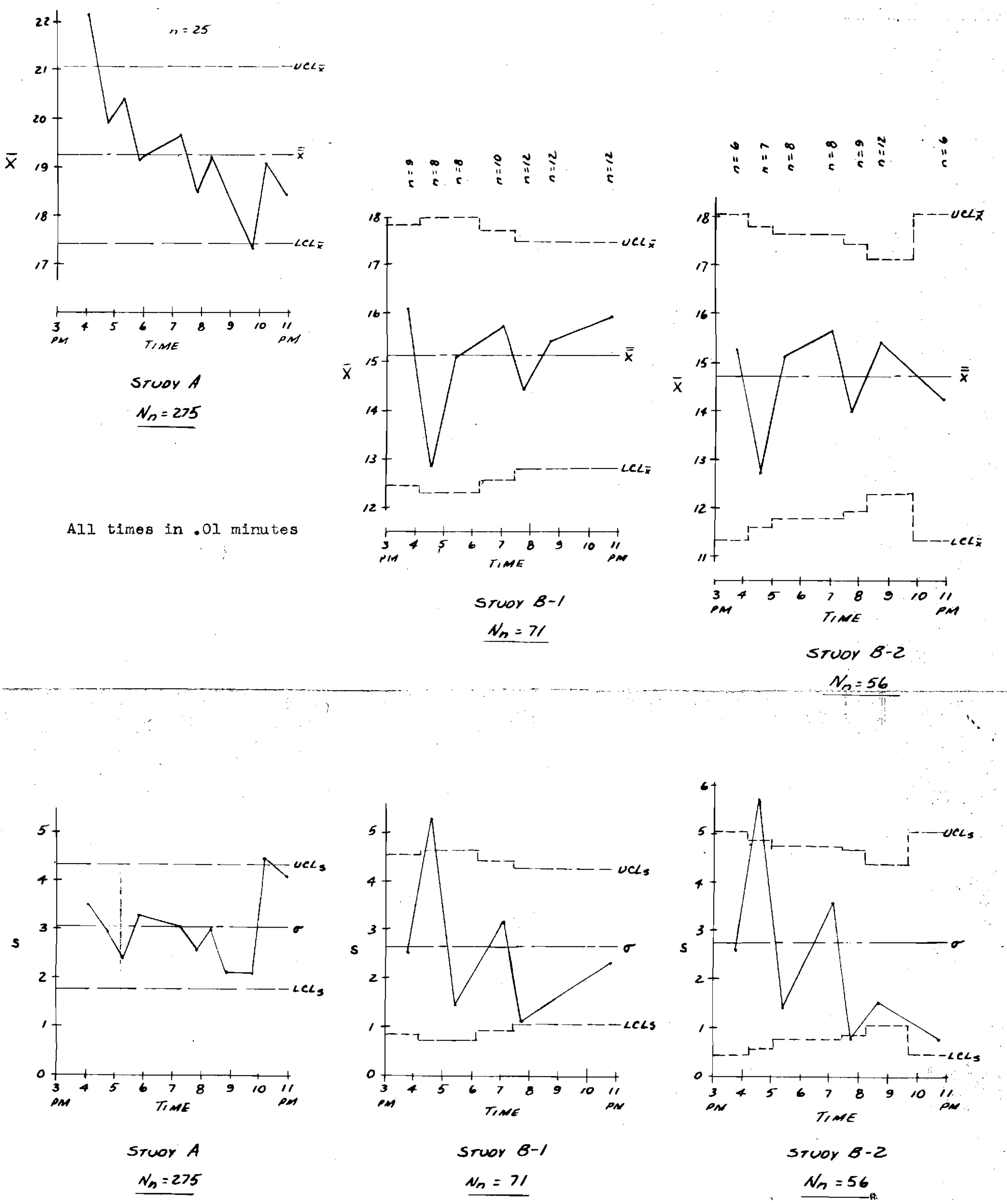
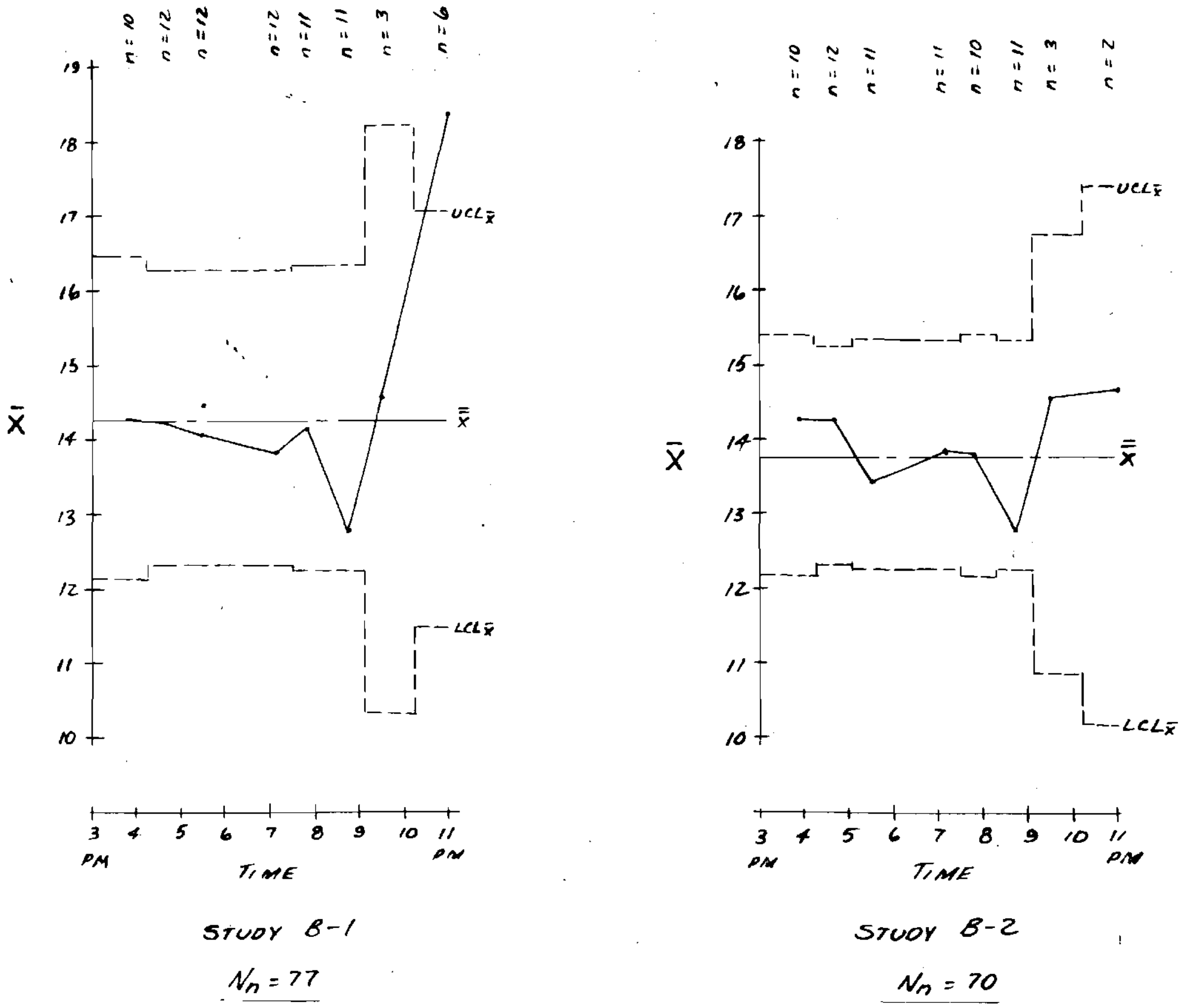


Figure 3. Control Charts for Means and Standard Deviations--Operator M



All times in .01 minutes

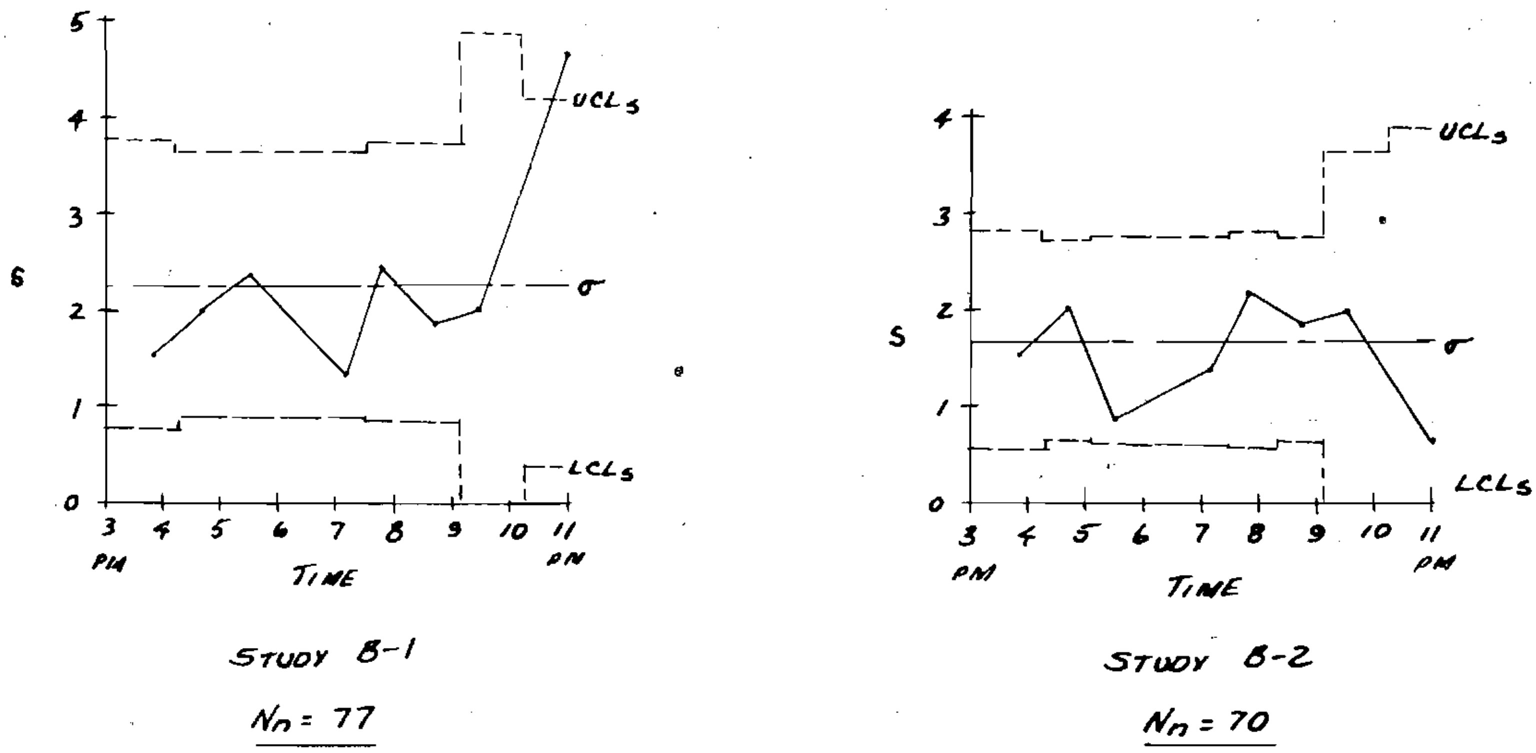
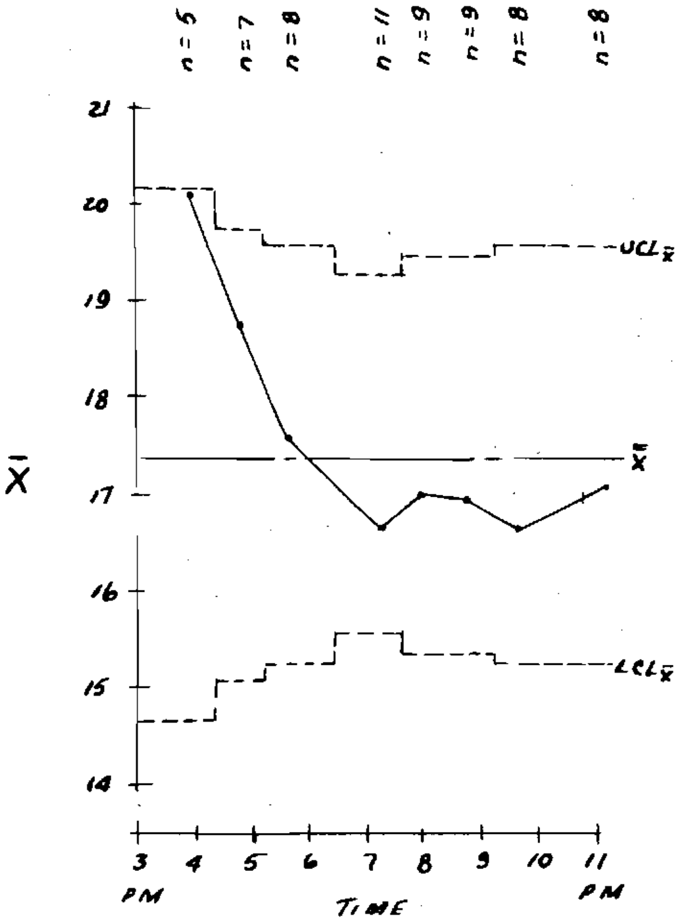
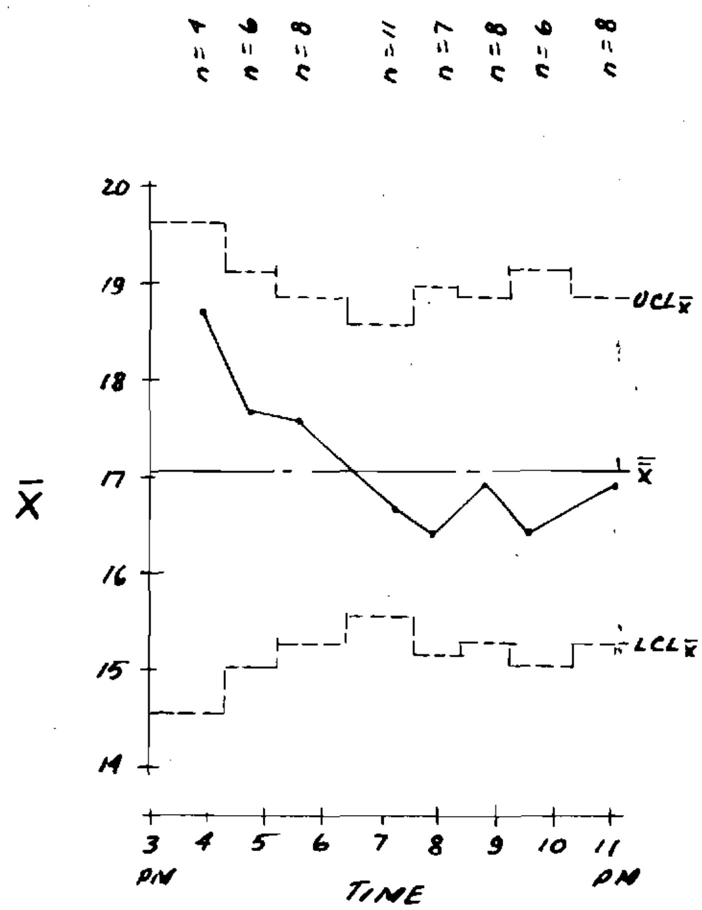


Figure 4. Control Charts for Means and Standard Deviations--Operator X





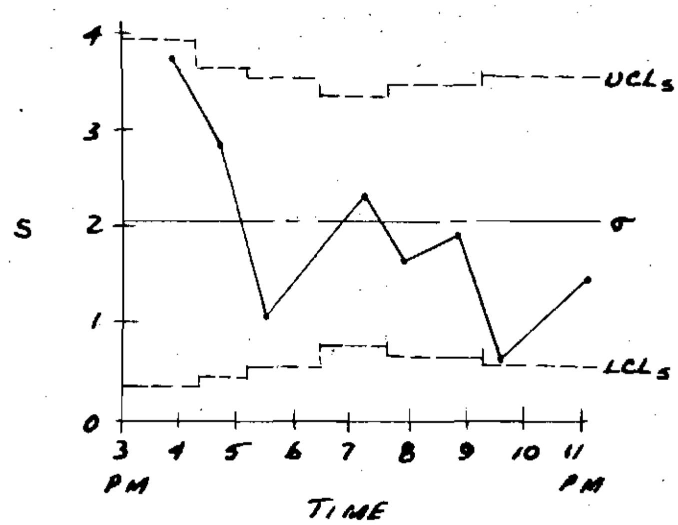
STUDY B-1

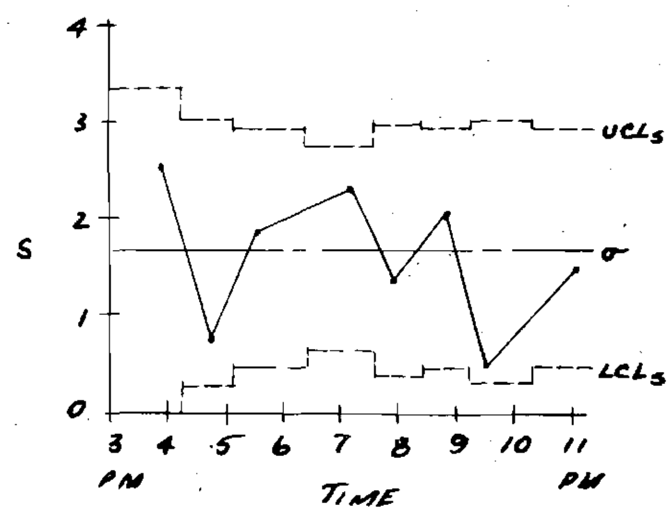
$N_n = 65$

STUDY B-2

$N_n = 58$

All times in .01 minutes





STUDY B-1

$N_n = 65$

STUDY B-2

$N_n = 58$

Figure 5. Control Charts for Means and Standard Deviations--Operator Z

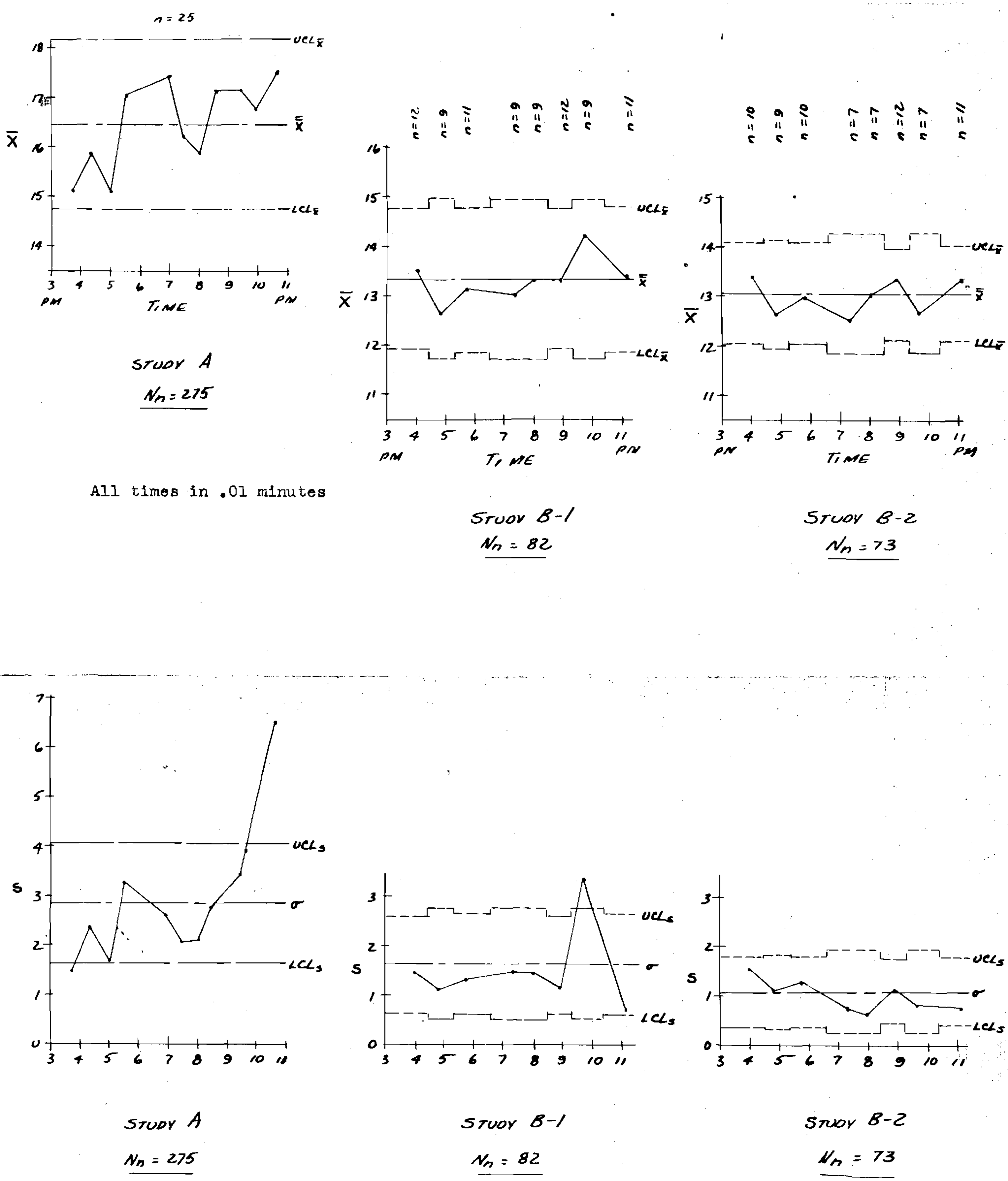


Figure 6. Control Charts for Means and Standard Deviations--Operator J

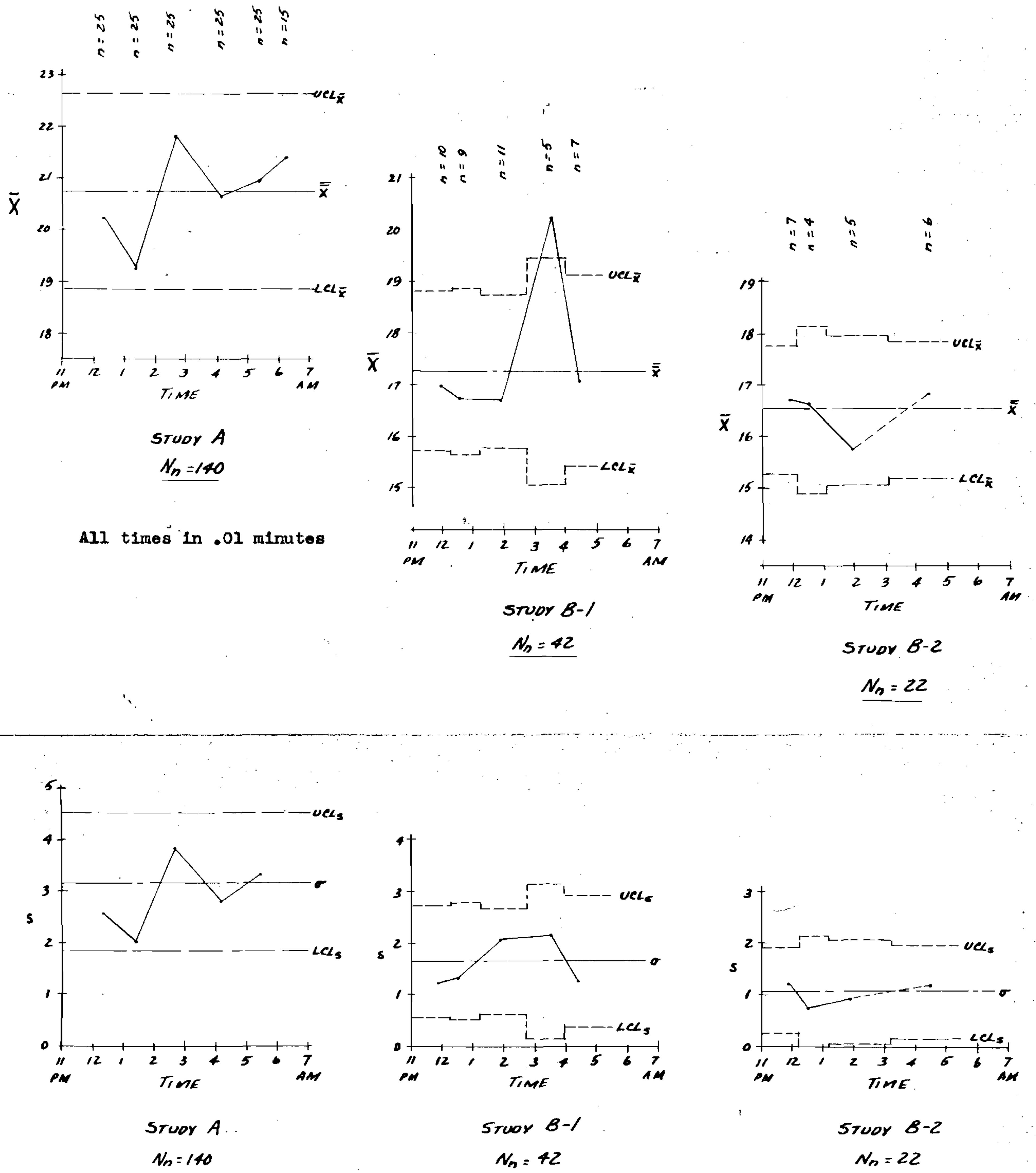
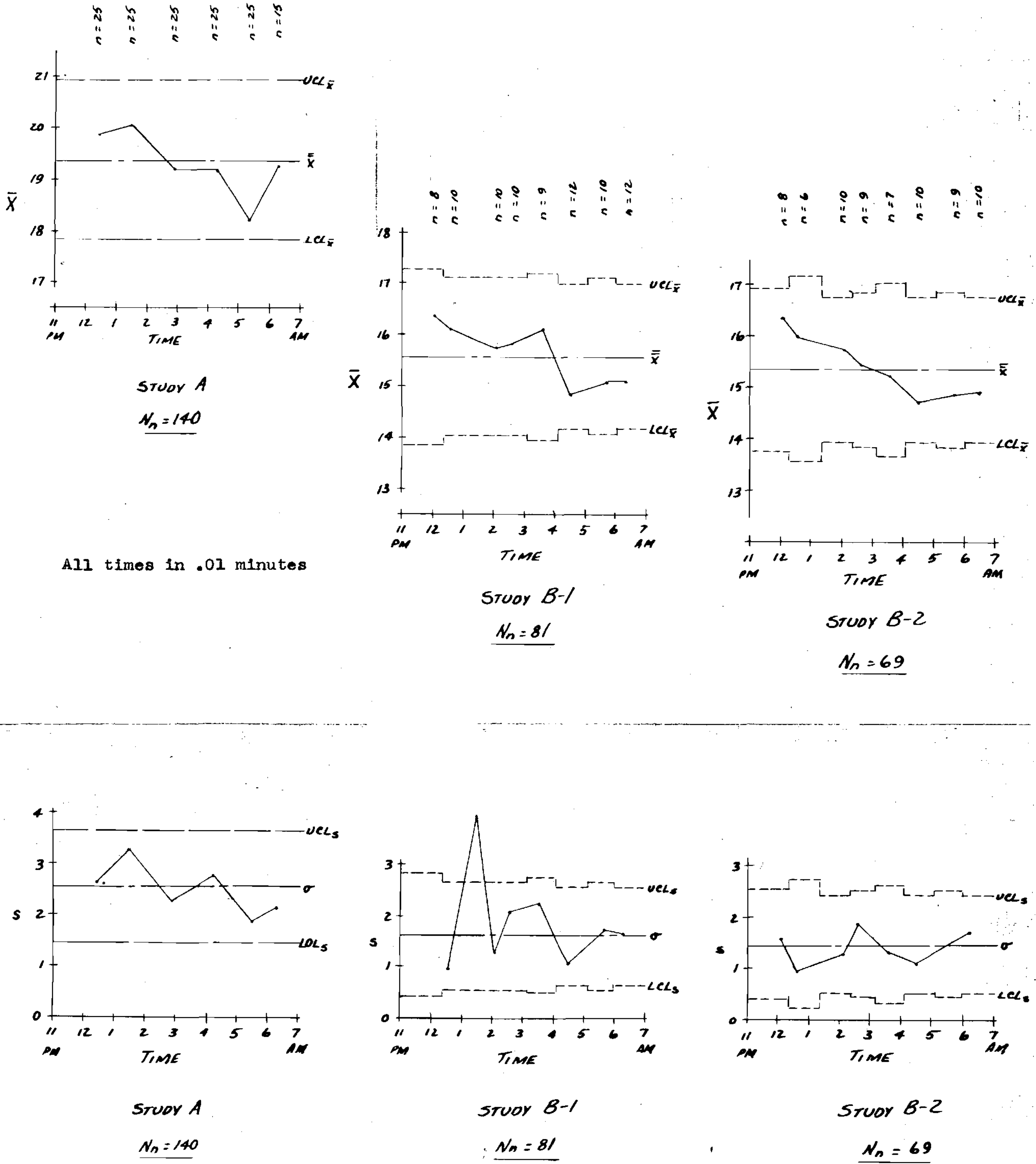


Figure 7. Control Charts for Means and Standard Deviations--Operator S



All times in .01 minutes

Figure 8. Control Charts for Means and Standard Deviations--Operator T

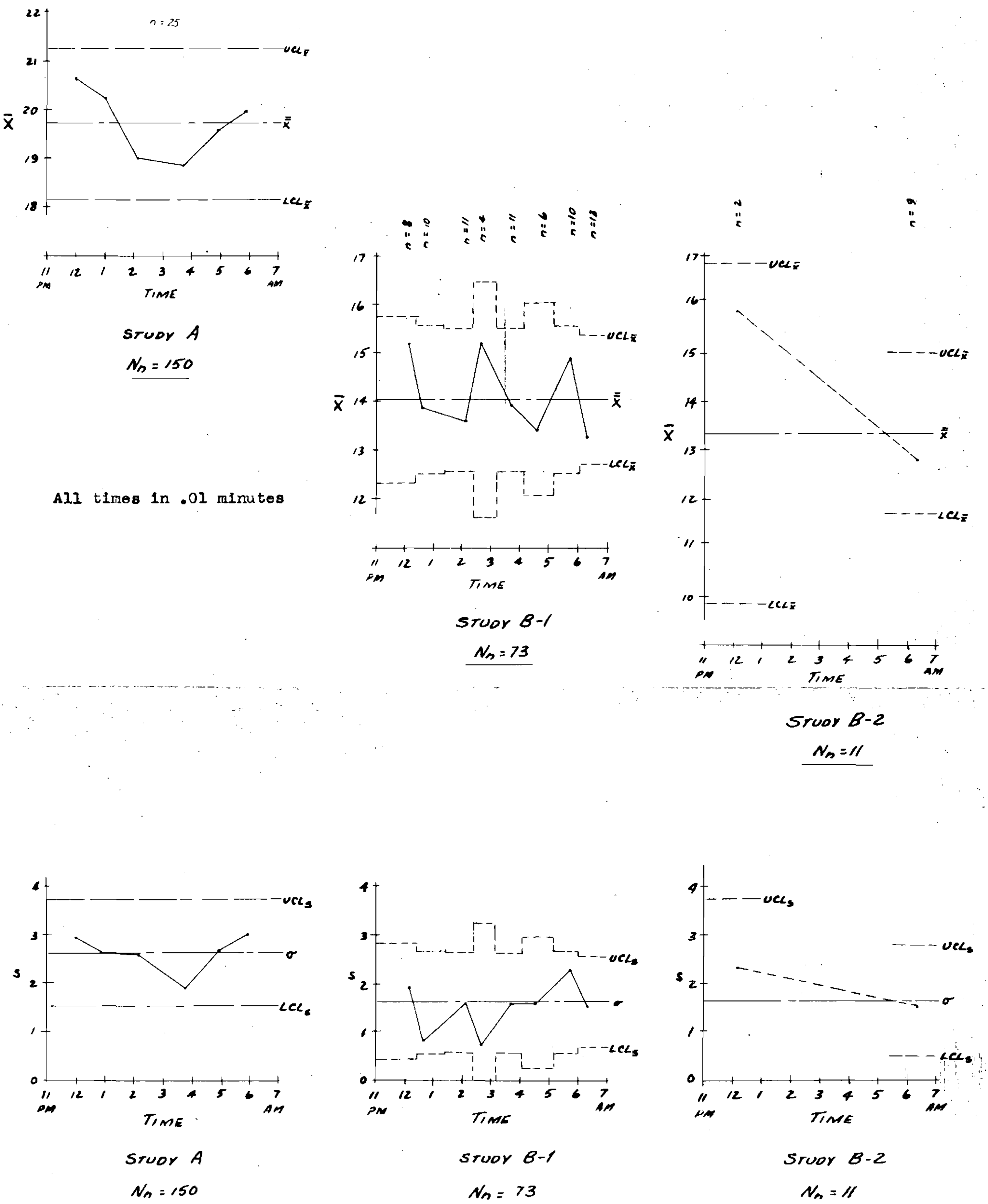
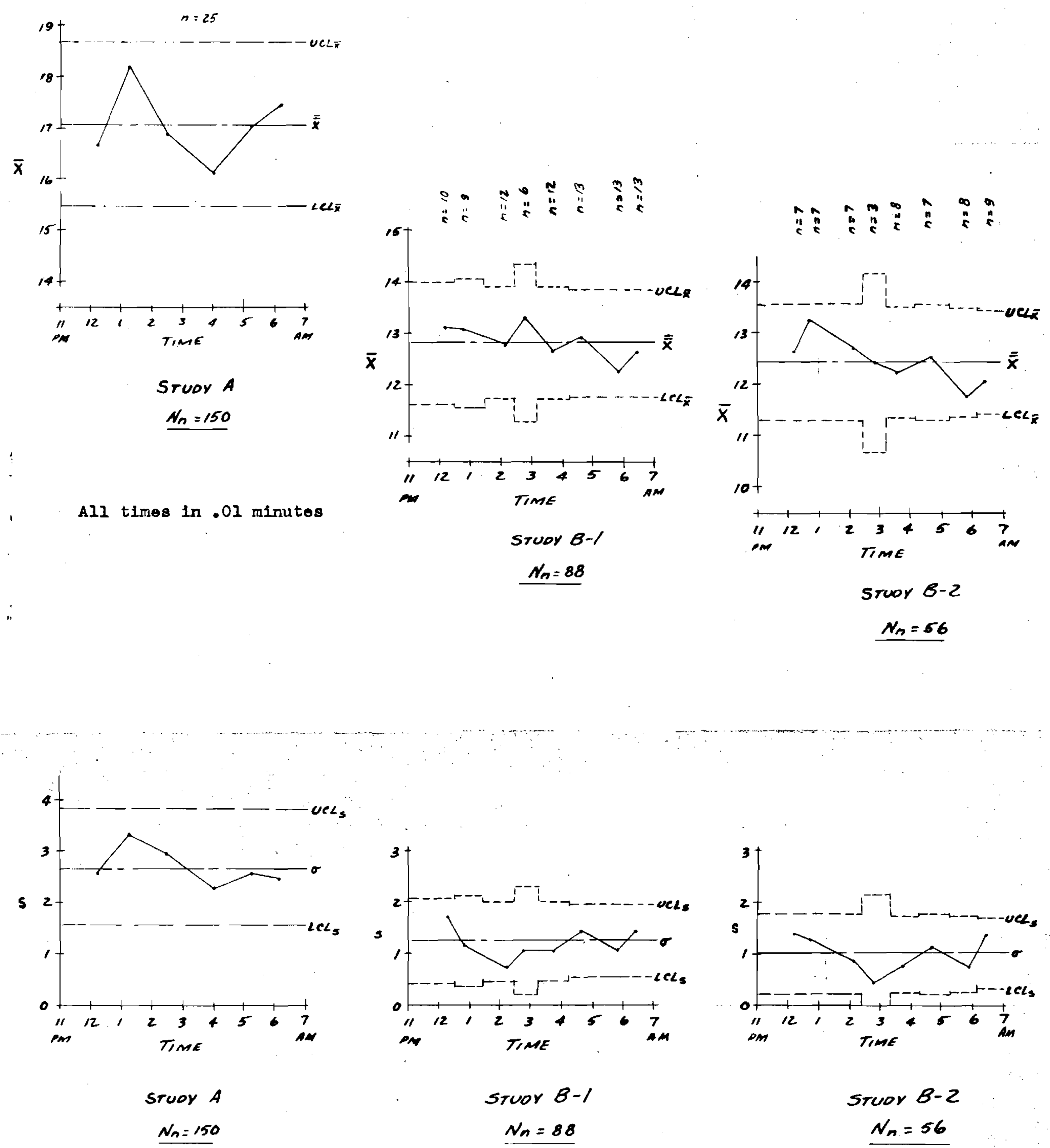
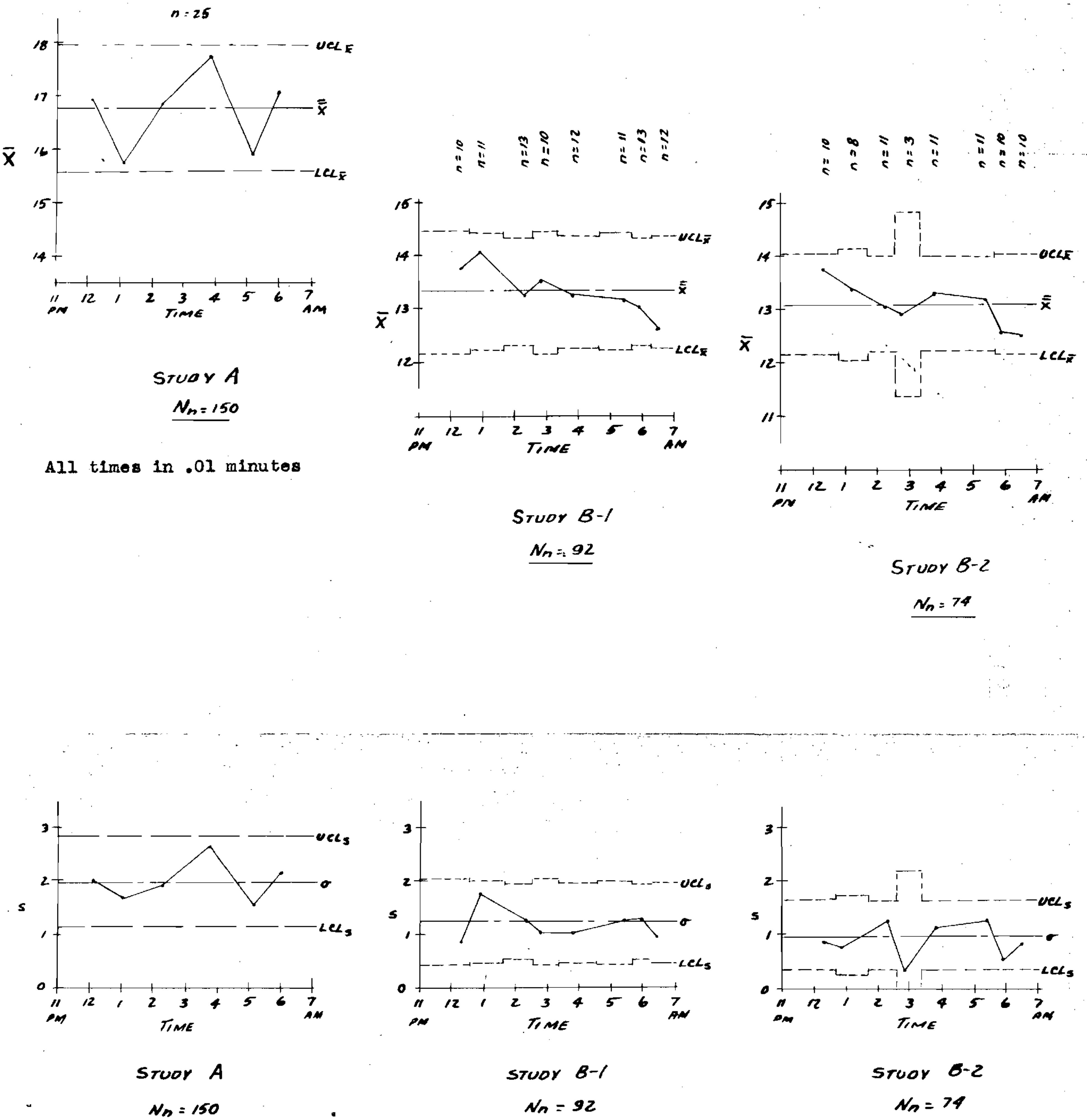


Figure 9. Control Charts for Means and Standard Deviations--Operator P



All times in .01 minutes

Figure 10. Control Charts for Means and Standard Deviations--Operator R



All times in .01 minutes

Figure 11. Control Charts for Means and Standard Deviations--Operator Q

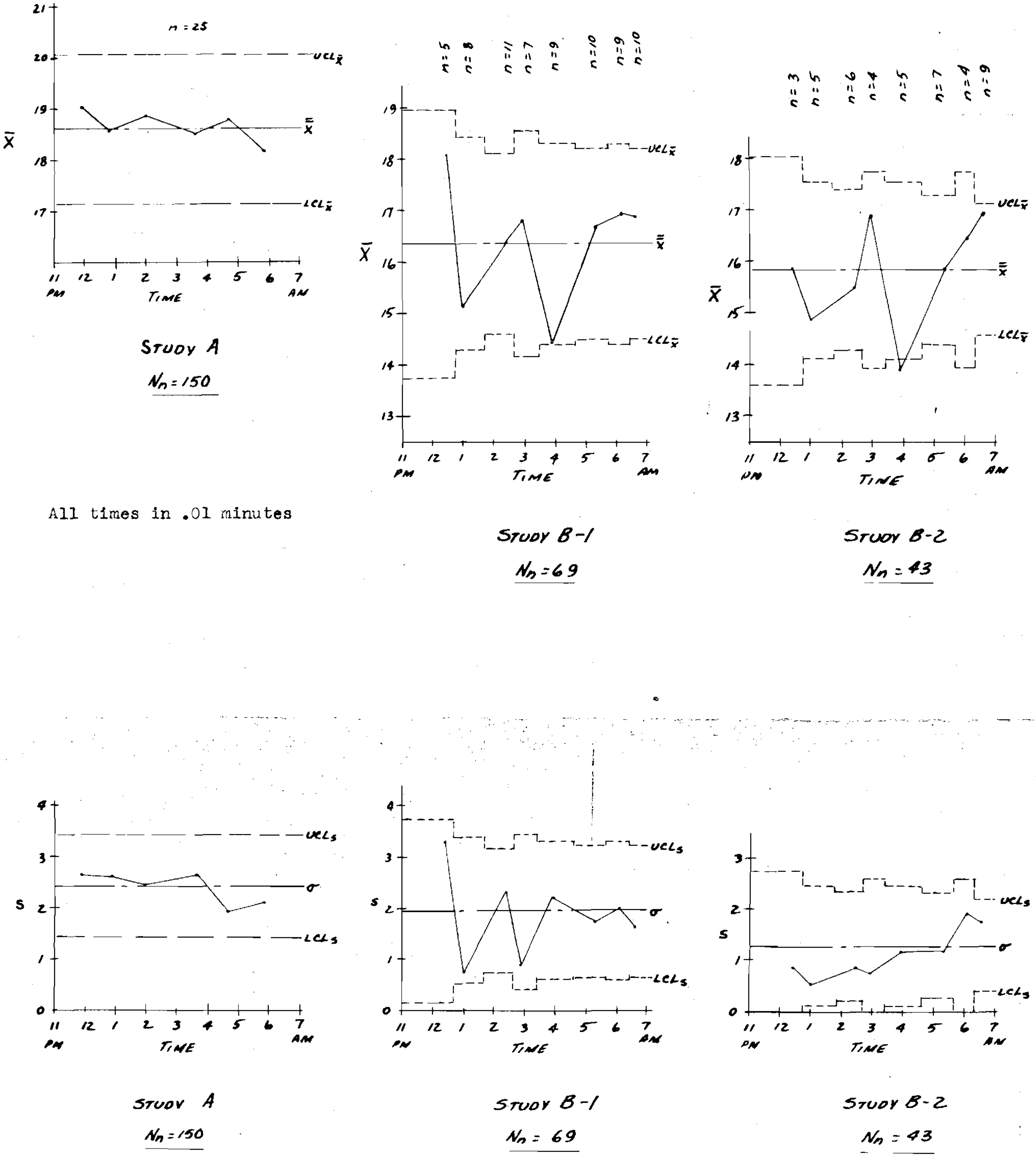
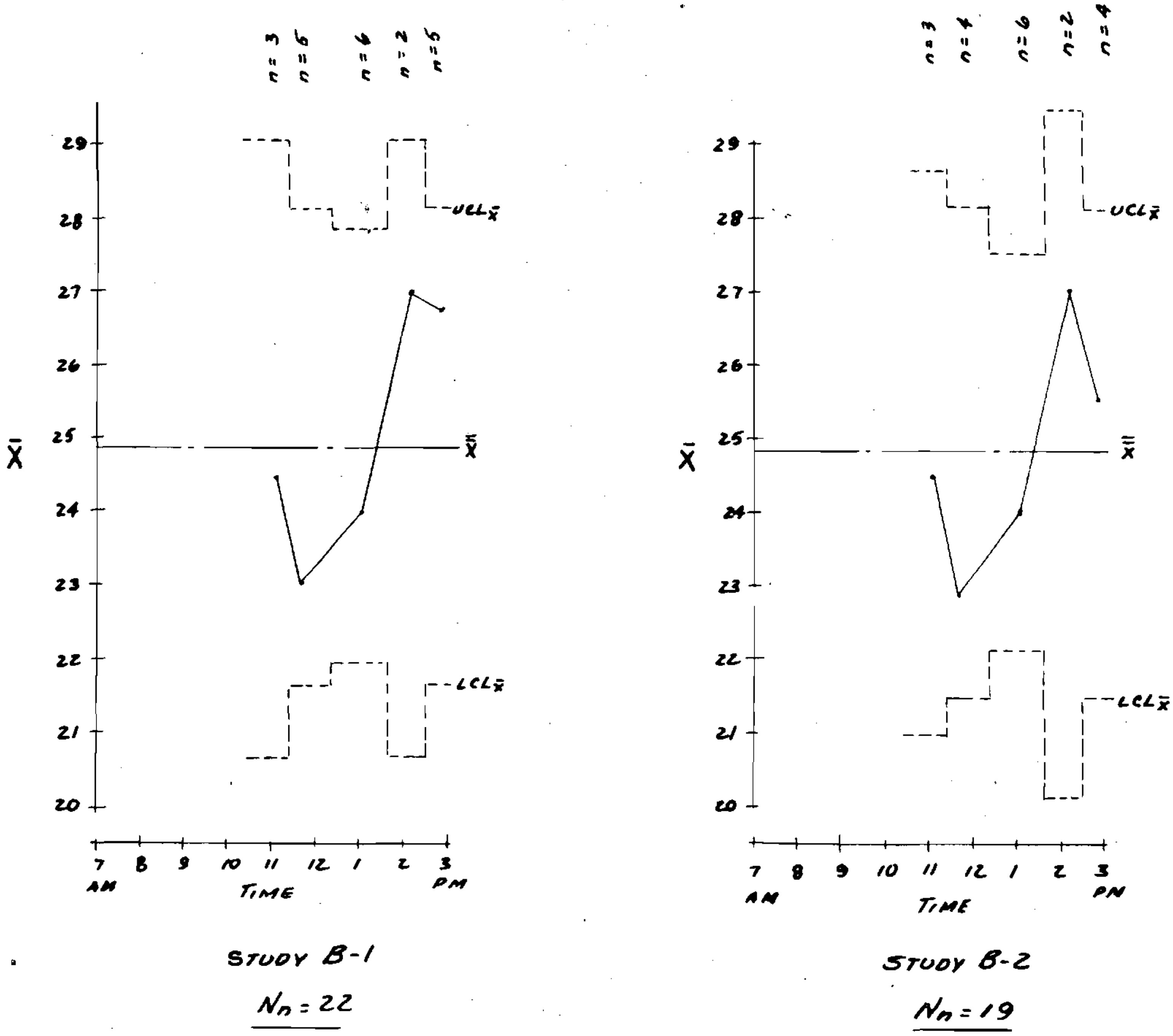


Figure 12. Control Charts for Means and Standard Deviations--Operator N



All times in .01 minutes

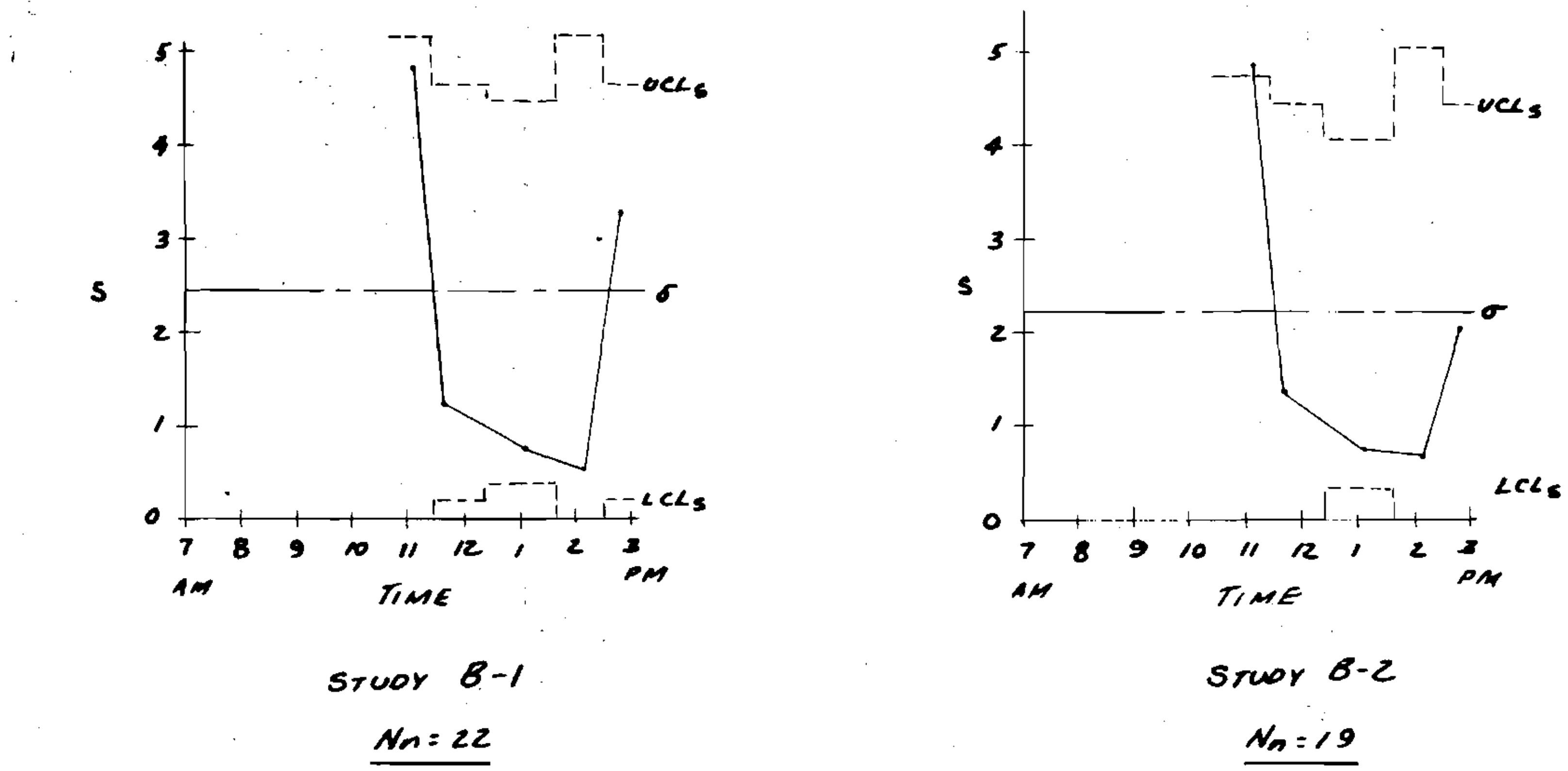


Figure 13. Control Charts for Means and Standard Deviations--Operator W

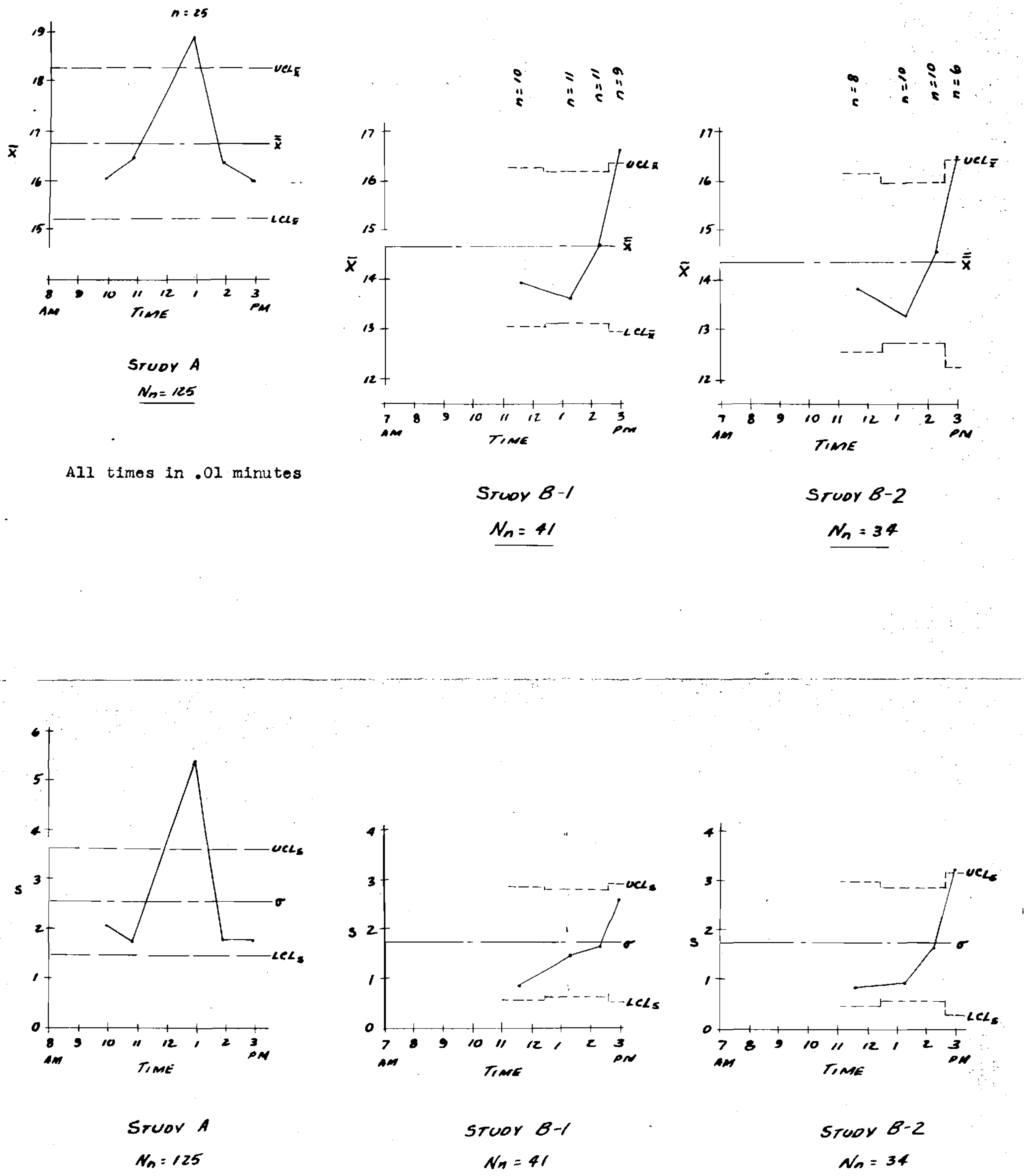


Figure 14. Control Charts for Means and Standard Deviations--Operator G

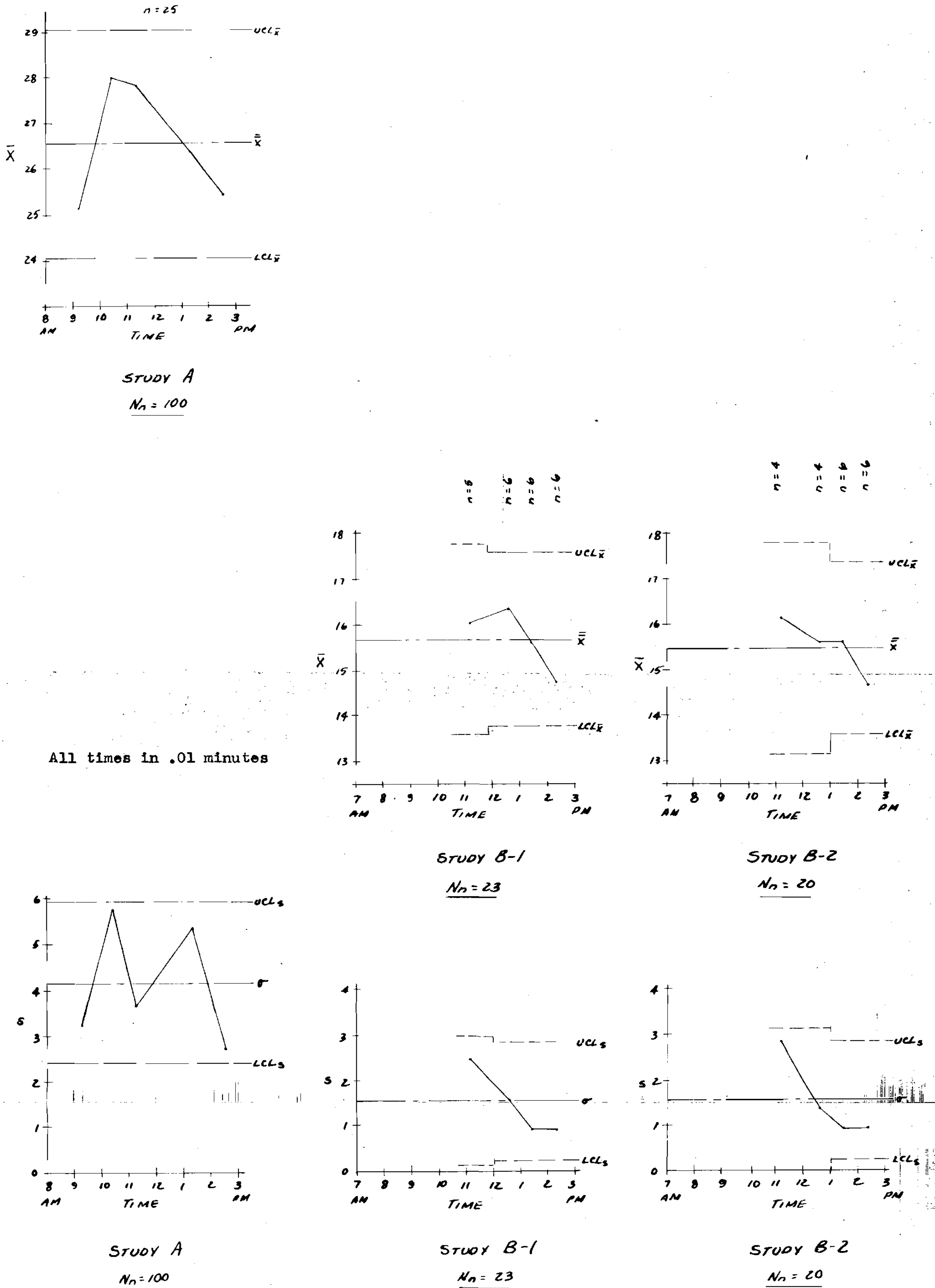


Figure 15. Control Charts for Means and Standard Deviations--Operator D

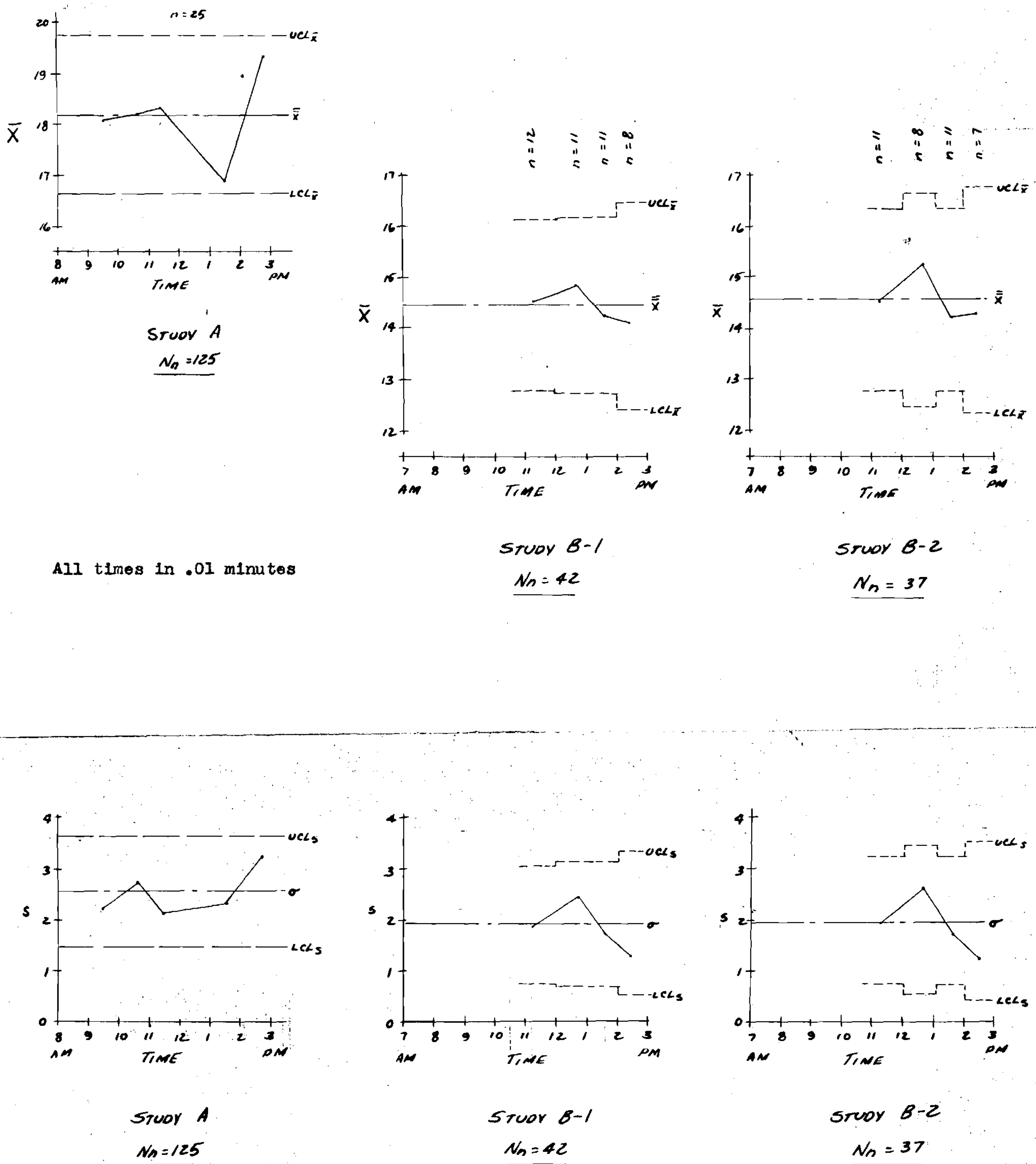
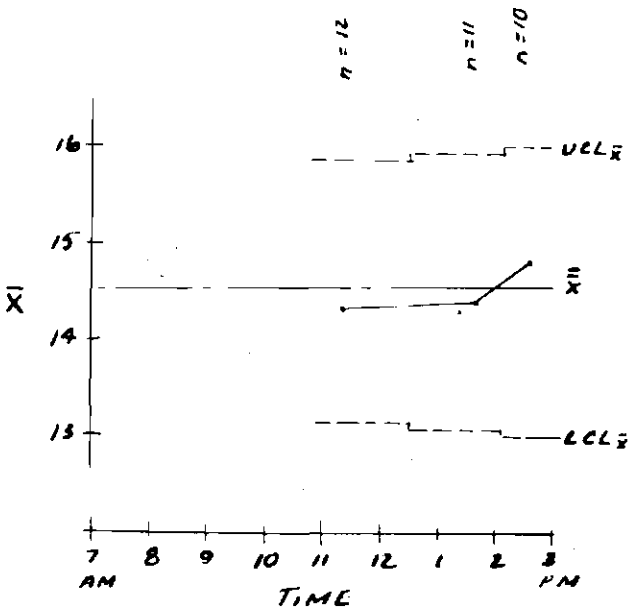
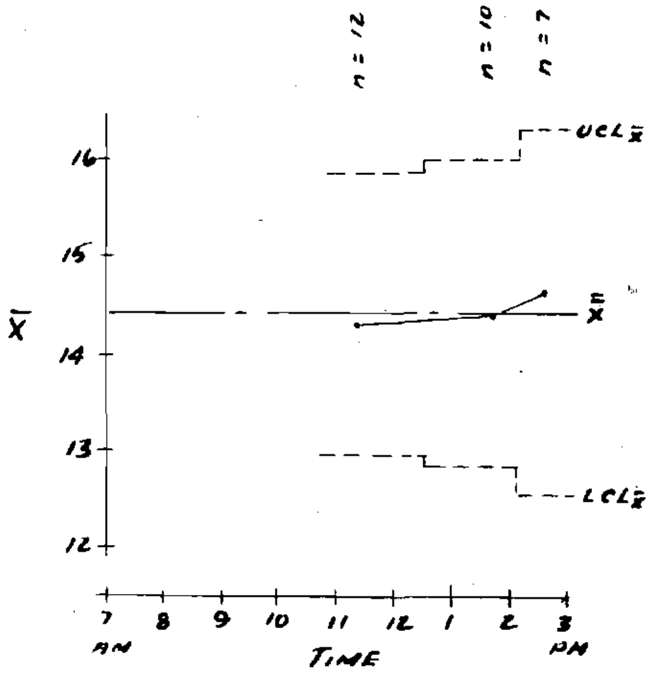


Figure 16. Control Charts for Means and Standard Deviations--Operator E



STUDY B-1

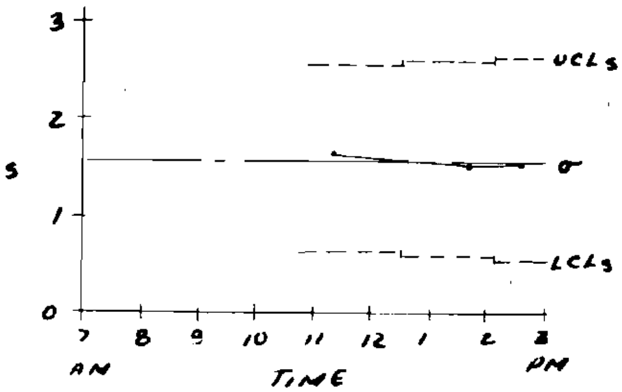
$N_n = 33$



STUDY B-2

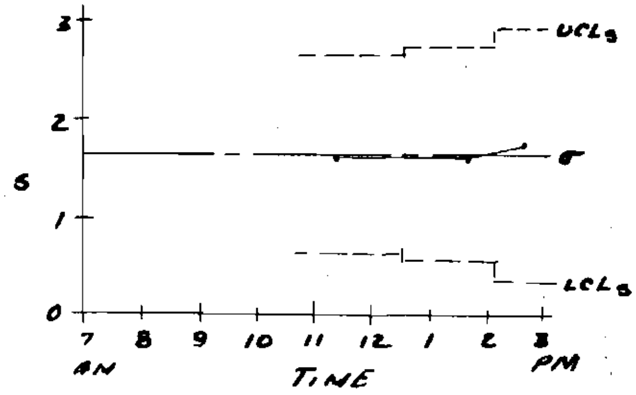
$N_n = 29$

All times in .01 minutes



STUDY B-1

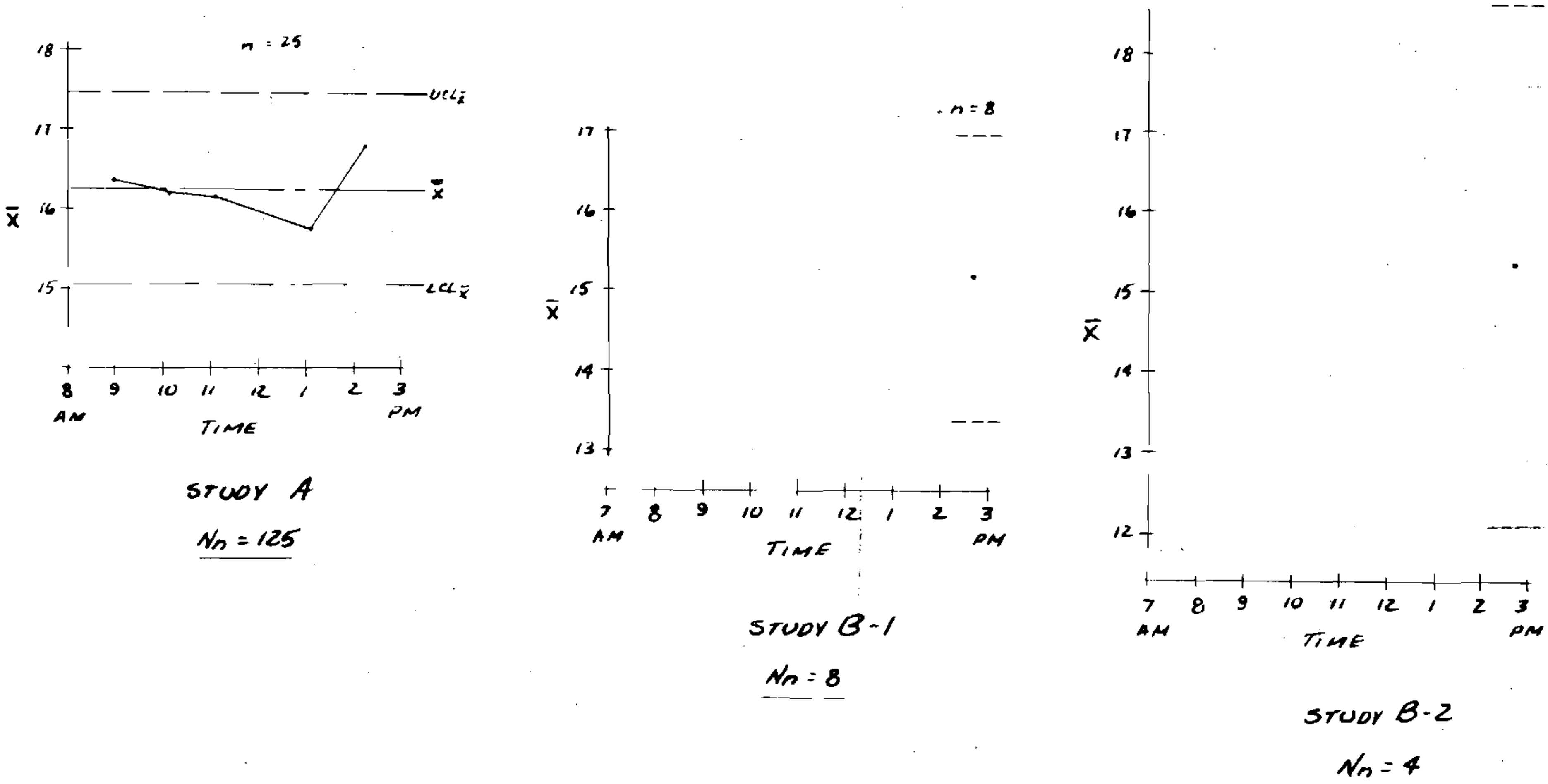
$N_n = 33$



STUDY B-2

$N_n = 29$

Figure 17. Control Charts for Means and Standard Deviations--Operator V



All times in .01 minutes

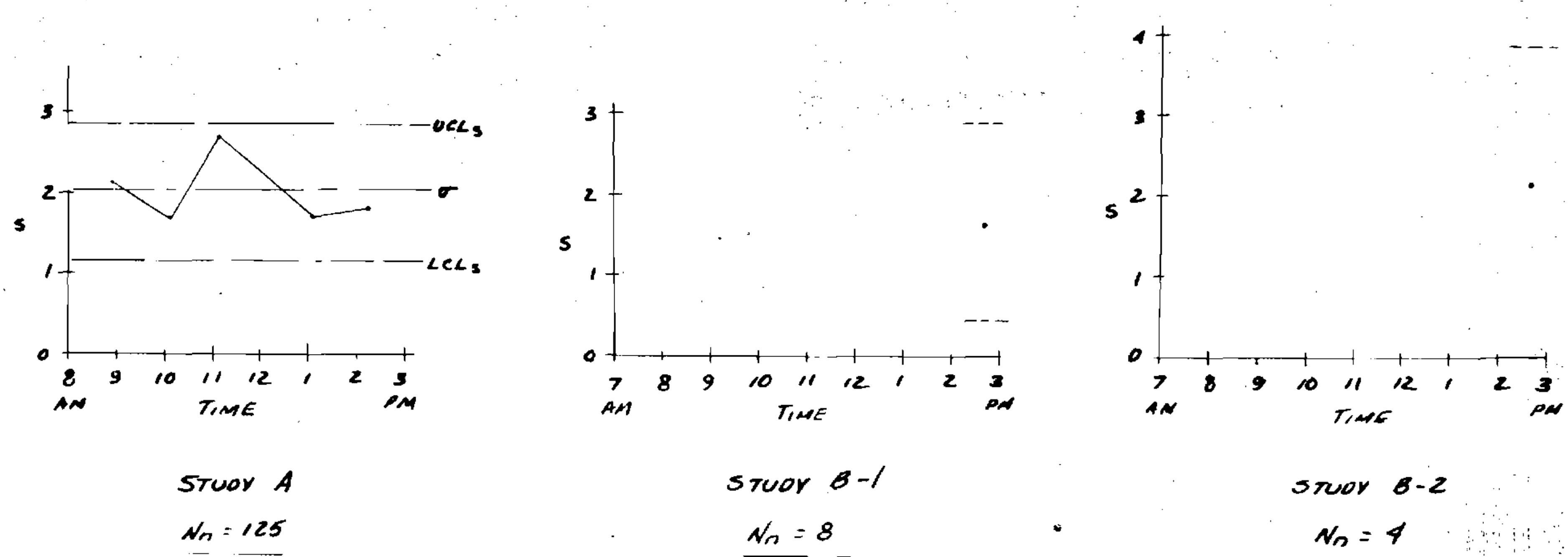


Figure 18. Control Charts for Means and Standard Deviations--Operator B

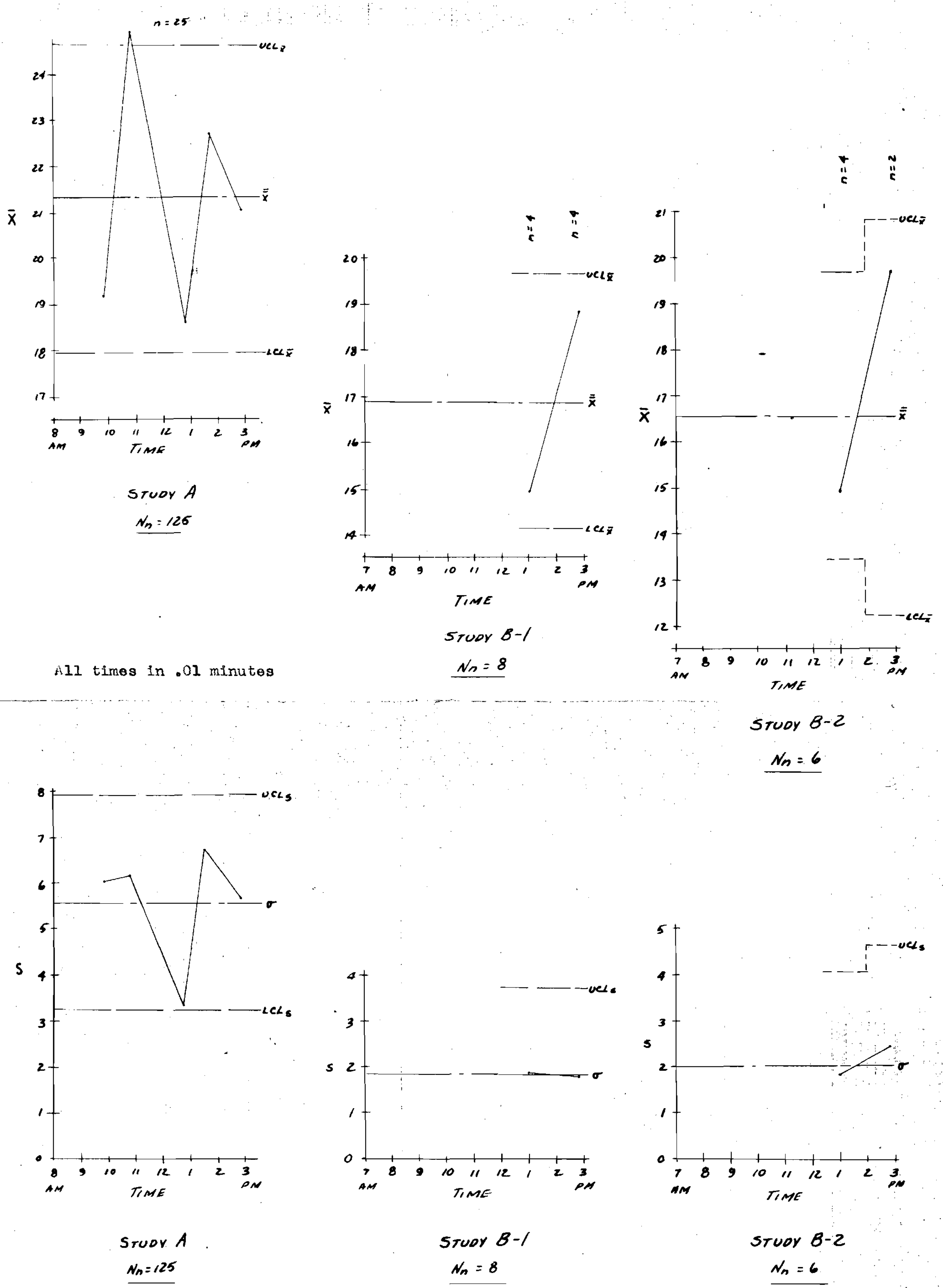
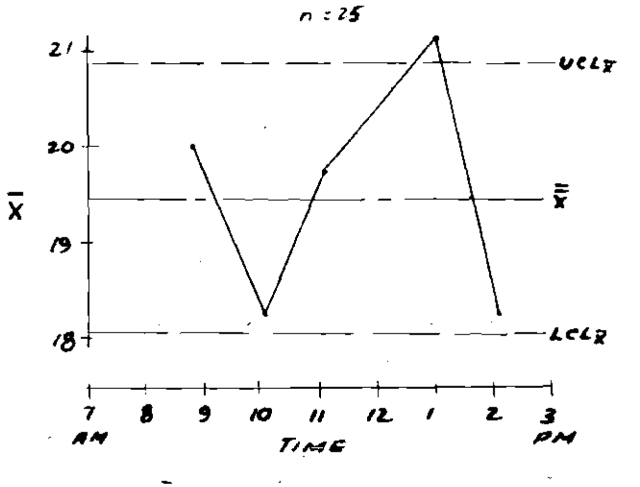
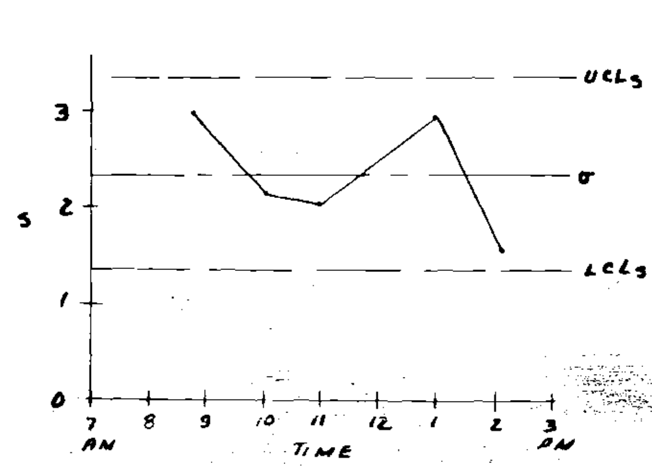


Figure 19. Control Charts for Means and Standard Deviations--Operator F

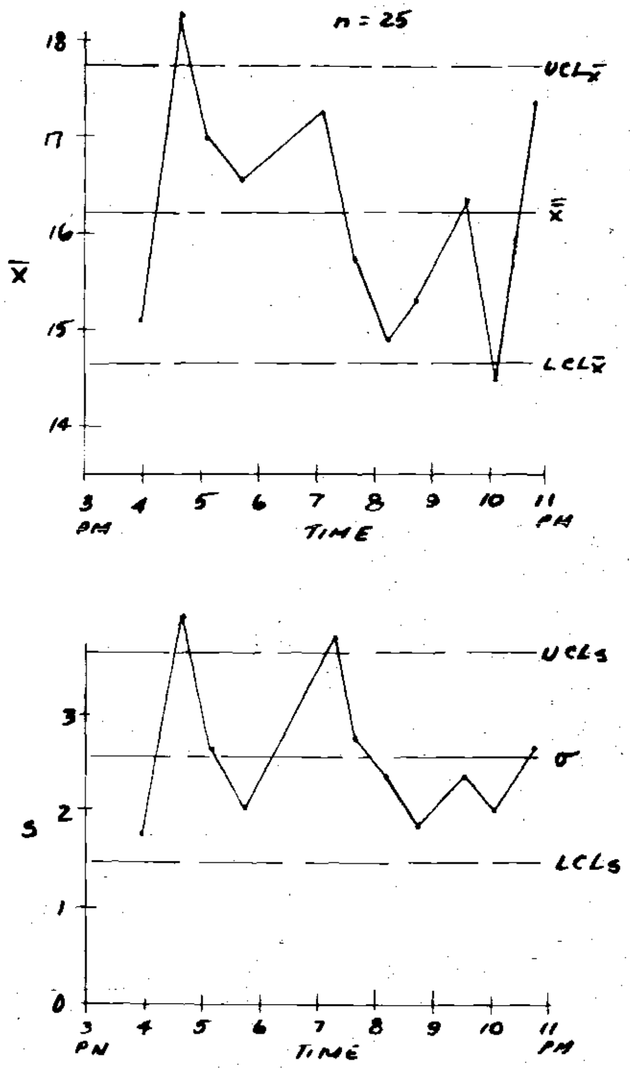


All times in .01 minutes



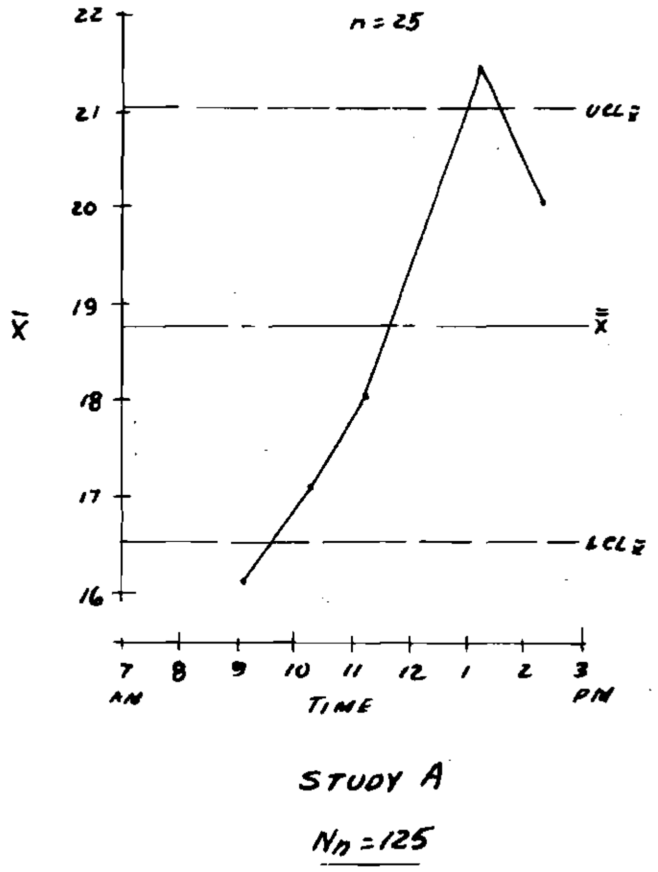
STUDY A — N_n = 125

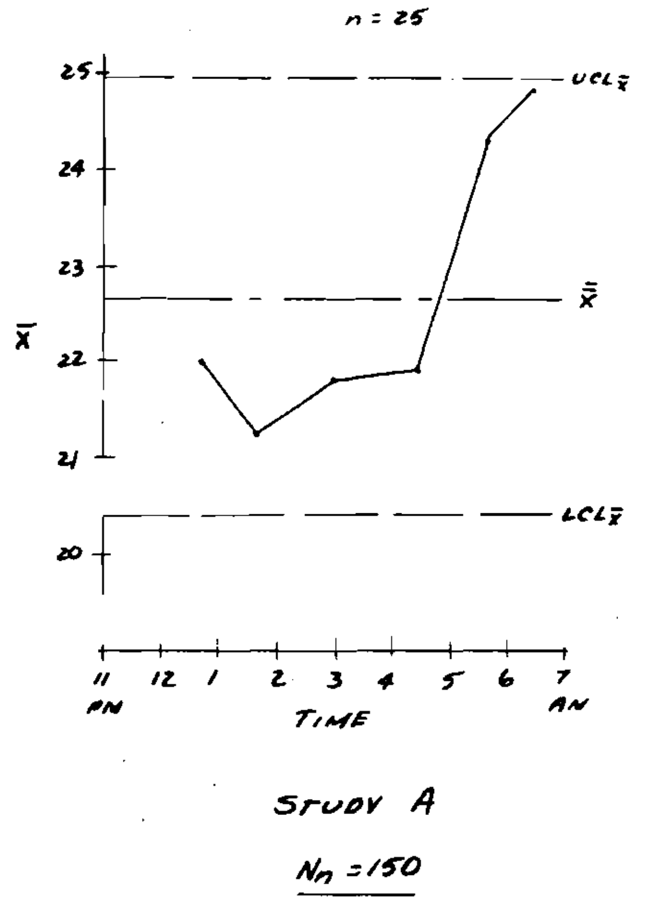
Figure 20. Control Charts for Means and Standard Deviations--Operator A



STUDY A — N_n = 275

Figure 21. Control Charts for Means and Standard Deviations--Operator L





All times in .01 minutes

All times in .01 minutes

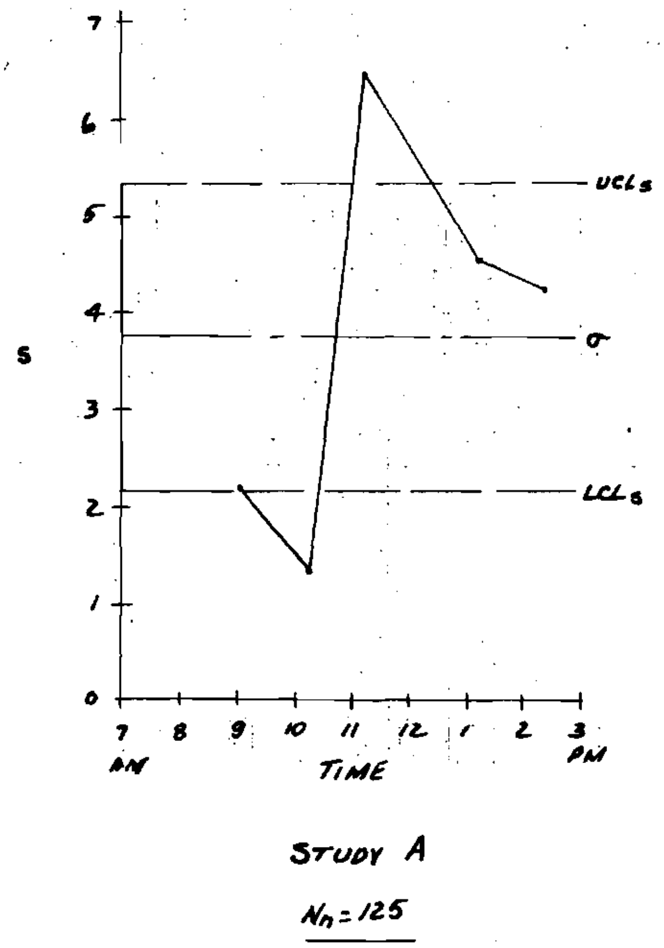


Figure 22. Control Charts for Means and Standard Deviations--Operator C

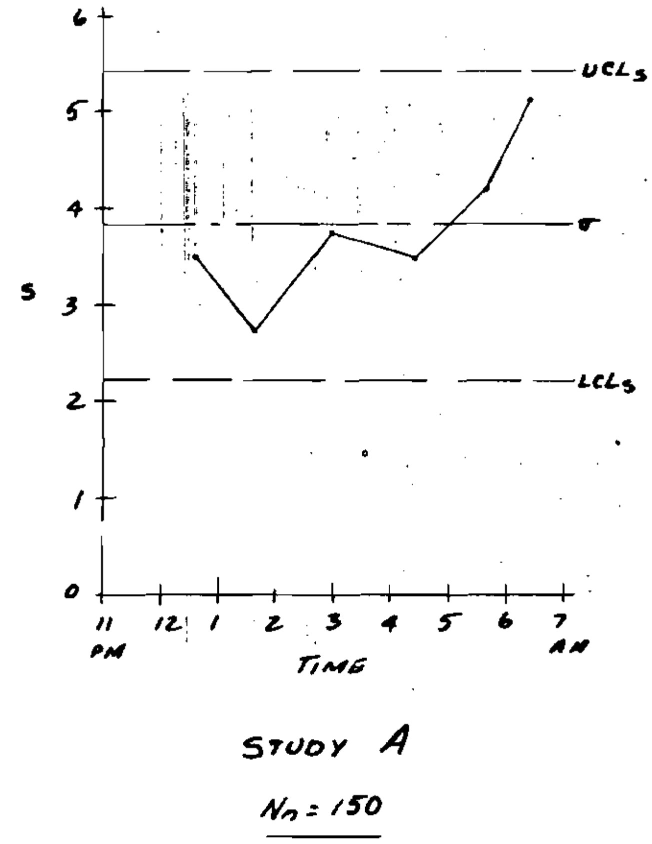


Figure 23. Control Charts for Means and Standard Deviations--Operator U

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

There are several limitations which affect the results of this study. These are:

(1) The data cover only one operation in one plant.

(2) In the final analysis, the data sufficiently represented only 12 operators.

(3) A limited number of variables were classified, and these variables were all visually detectable.

(4) In some instances, the individual shot sample contained only two or three measurements as a result of data elimination as discussed previously.

Conclusions

Within the frame of the limitations set forth above, the following conclusions can be drawn:

(1) The evidence is inconclusive that the removal of the assignable causes of variation, as selected by the methods and criteria stated previously, will significantly affect the statistical stability of modified cycle times as indicated on $\bar{X}$ and s control charts.

(2) The presence, in a shot of several cycle times, of one or more of the variables herein classed as assignable may or may not be indicated on $\bar{X}$ and s control charts as would normally be expected, viz., points outside the three-sigma control limits.

(3) Operator cycle performance times from a manually-controlled, repetitive type assembly operation are not unstable solely on account of the presence of commonly-known assignable causes of variation, such as typified by the variables noted in this study.

(4) If operator cycle performance times <u>are</u> inherently stable for an operation of <u>this</u> type, and if instability is caused only by the presence of assignable causes of variation, then micromotion analysis fails to completely identify all of these assignable causes.

<u>Discussion</u>.--Certain characteristics of the control charts for means and standard deviations with the selected variables excluded as compared with the charts with variables included are worthy of additional note.

A rigid prediction of the changes which will occur in these charts in an analysis such as has been carried out in this study appears to be without sound basis. This is exemplified clearly in both the $\bar{x}$ and s charts with variables excluded by the fact that some charts indicated a gain in stability, some experienced a loss of initial stability, some revealed the presence of previously undetected trends, and one showed no apparent change.

A study of the nature of the elements selected as assignable cause variables suggests several hypotheses as to the reasons for this varying effect. All six variables are deviations which are immediately obvious both to the operator and to the observer, be the observer another operator, a supervisor, or a time study analyst as in this case. The usual delaying effect of these variables would, of course, be reflected in the operator's daily production record. It is possible that being cognizant of these facts the ambitious operator would desire to make up this lost production.

With this thought in mind the original film analysis data were studied again, and it was observed that the occurrence of these visually detectable variables within the work performance cycle often appeared to have effect upon the successive times and the resulting shot mean. Close analysis of the data showed that many cycles containing these variables which normally increase the cycle time are followed immediately by a cycle time considerably below the average for the shot. This suggests that the operator frequently does attempt to compensate for the manual error and consequent long performance time in one cycle by increasing her pace in the next. Were this consistently true, the immediate delay effect of most assignable-cause variables would become lost to detection in an averaging of several cycles into a shot mean. If only sporadically true, some assignable-cause variables would be notice and eliminated, some would not. The effect of such a variable removal would then be unpredictable.

Here, then, is a noteworthy difference between the inherent validity of a visual interpretation of the control charts for production times and those for product-quality measures. Quality control charts will invariably identify an assignable cause of variation so long as the affected part or product is included in the measurement sample. But with the ability to compensate being present in human performance, assignable causes can and may be concealed even within a sample.

It appears, however, that time variation in a human operator, in a magnitude which would be considered highly excessive in a machine operation, is a natural thing caused partly by obvious assignable causes but also partly due to the operator's own motivation. This motivation may stem from a desire to lessen monotony and subsequent fatigue, to achieve recognition for production in amounts higher than is continually possible from a physical health standpoint, or from many other such behavior characteristics. Unnecessarily strict control of these performance times, which infers control upon certain personal motivations, may be neither scientifically achievable or sociologically feasible. Nevertheless, control of extraneous or assignable causes of variation which are of a more objective nature remains essential in the determination of equitable performance time standards.

Recommendations

It is recommended that additional study be directed toward:

(1) The behavior and background of operators found to be consistently stable regarding performance times, and similarly to those found consistently unstable.

(2) The appropriateness of strict adherence to techniques and discipline of statistical quality control when dealing with performance times, with particular regard to:

a. Three-sigma control limits.

b. Conclusion of instability when a very small percentage of points fall outside control chart limits.

c. The significance of runs and trends regarding stability.

(3) The influence of work pace on the stability of cycle times.

APPENDIX

SAMPLE CALCULATIONS

The calculations shown are for the Study B-1 data (variables included) concerning Operator H. All times are in .01 minutes.

Shot mean cycle time (3:30 P. M. shot):

$$\bar{x} = \frac{\Sigma x}{n} = \frac{118.9}{7} = 16.99$$

Operator's mean cycle time:

$$\bar{\bar{x}} = \frac{\bar{x}_1 n_1 + \bar{x}_2 n_2 + \ldots \bar{x}_k n_k}{n_1 + n_2 + \ldots n_k}$$

$$\bar{\bar{x}} = \frac{1013.100}{66} = 15.350$$

Shot standard deviation (3:30 P. M. shot):

$$s = \sqrt{\frac{\Sigma x^2}{n-1} - \frac{(\Sigma x)^2}{n(n-1)}}$$

$$s = \sqrt{\frac{2034.54}{(7-1)} - \frac{(118.90)^2}{7(7-1)}}$$

$$s = 1.580$$

Unbiased estimate of universe standard deviation:

$$\sigma^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2 + \ldots (n_k-1)s_k^2}{n_1 + n_2 + \ldots n_k - k}$$

$$\sigma^2 = \frac{179.753352}{58}$$

$$\sigma = 1.760$$

Control limits for $\bar{x}$ chart:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A\sigma$$

$$= 15.350 + (1.13)(1.760)$$

$$UCL_{\bar{x}} = 17.339$$

$$LCL_{\bar{x}} = 15.350 - (1.13)(1.760)$$

$$LCL_{\bar{x}} = 13.361$$

Control limits for s chart:

$$UCL_s = B_5 \sigma$$

$$= (1.78)(1.760)$$

$$UCL_s = 3.133$$

$$LCL_s = B_6 \sigma$$

$$= (0.21)(1.760)$$

$$LCL_s = 0.370$$

Table 4. Control Chart Data -- Study A

Oper.		1	2	3	4	5			
A	$\bar{x}$	20.00	18.28	19.70	21.16	18.28	$\bar{\bar{x}}$ = 19.484	$UCL_{\bar{x}}$ = 20.887	$LCL_{\bar{x}}$ = 18.081
	s	3.00	2.15	2.04	2.95	1.55	σ = 2.338	UCL_s = 3.320	LCL_s = 1.356
B	$\bar{x}$	16.36	16.24	16.16	15.76	16.80	$\bar{\bar{x}}$ = 16.264	$UCL_{\bar{x}}$ = 17.475	$LCL_{\bar{x}}$ = 15.053
	s	2.16	1.70	2.70	1.70	1.83	σ = 2.018	UCL_s = 2.866	$LCL_{\bar{x}}$ = 1.170
C	$\bar{x}$	16.64	17.10	18.08	21.48	20.60	$\bar{\bar{x}}$ = 18.780	$UCL_{\bar{x}}$ = 21.036	$LCL_{\bar{x}}$ = 16.524
	s	2.19	1.32	6.49	4.56	4.24	σ = 3.760	UCL_s = 5.339	LCL_s = 2.181
D	$\bar{x}$	25.16	28.00	27.84	26.36	25.48	$\bar{\bar{x}}$ = 26.568	$UCL_{\bar{x}}$ = 29.062	$LCL_{\bar{x}}$ = 24.074
	s	3.29	5.74	3.65	5.37	2.73	σ = 4.156	UCL_s = 5.902	LCL_s = 2.410
E	$\bar{x}$	18.10	18.20	18.32	16.90	19.36	$\bar{\bar{x}}$ = 18.176	$UCL_{\bar{x}}$ = 19.714	$LCL_{\bar{x}}$ = 16.638
	s	2.27	2.77	2.17	2.35	3.26	σ = 2.564	UCL_s = 3.641	LCL_s = 1.487
F	$\bar{x}$	19.20	24.96	18.64	22.72	21.08	$\bar{\bar{x}}$ = 21.320	$UCL_{\bar{x}}$ = 24.276	$LCL_{\bar{x}}$ = 17.964
	s	6.03	6.15	3.33	6.76	5.70	σ = 5.594	UCL_s = 7.943	LCL_s = 3.245

Table 4. Control Chart Data -- Study A
(Continued)

Oper.		1	2	3	4	5			
G	$\bar{x}$	16.04	16.48	18.88	16.34	16.00	$\bar{\bar{x}} = 16.748$	$UCL_{\bar{x}} = 18.272$	$LCL_{\bar{x}} = 15.224$
	s	2.09	1.73	5.35	1.77	1.76	$\sigma = 2.540$	$UCL_s = 3.607$	$LCL_s = 1.473$

Table 4. Control Chart Data -- Study A
(Continued)

Oper.		1	2	3	4	5	6	7	8	9	10	11
H	$\bar{x}$	24.04	23.92	22.20	22.00	22.87	22.36	19.28	19.48	19.32	18.04	18.28
	s	4.62	3.33	4.54	3.93	2.75	3.91	2.95	3.50	2.97	3.07	2.81
		$\bar{\bar{x}} = 21.163$		$UCL_{\bar{x}} = 23.308$		$LCL_{\bar{x}} = 19.0.8$		$\sigma = 3.575$		$UCL_s = 5.076$		$LCL_s = 2.074$
J	$\bar{x}$	15.12	15.92	15.08	17.04	17.44	16.20	15.88	17.12	17.12	16.76	17.52
	s	1.48	2.40	1.69	3.27	2.60	2.08	2.11	2.80	3.46	3.11	6.54
		$\bar{\bar{x}} = 16.473$		$UCL_{\bar{x}} = 18.193$		$LCL_{\bar{x}} = 14.753$		$\sigma = 2.867$		$UCL_s = 4.071$		$LCL_s = 1.663$
K	$\bar{x}$	16.04	16.32	16.00	18.28	17.56	17.52	16.20	17.08	17.00	15.84	17.84
	s	4.05	3.60	2.81	4.76	2.57	3.71	2.61	4.44	3.00	2.38	3.58
		$\bar{\bar{x}} = 16.880$		$UCL_{\bar{x}} = 18.926$		$LCL_{\bar{x}} = 14.834$		$\sigma = 3.410$		$UCL_s = 4.842$		$LCL_s = 1.978$
L	$\bar{x}$	15.12	18.32	17.00	16.56	17.28	15.72	14.88	15.28	16.32	14.44	17.34
	s	1.77	4.03	2.66	2.04	3.81	2.79	2.35	1.84	2.36	2.02	2.68
		$\bar{\bar{x}} = 16.205$		$UCL_x = 17.751$		$LCL_x = 14.659$		$\sigma = 2.577$		$UCL_s = 3.659$		$LCL_s = 1.495$

Table 4. Control Chart Data -- Study A
(Continued)

Oper.		1	2	3	4	5	6	7	8	9	10	11
M	$\overline{x}$	22.16	19.80	20.40	19.12	19.68	18.48	19.24	18.00	17.32	19.08	18.44
	s	3.51	2.95	2.45	3.29	3.06	2.52	2.99	2.10	2.09	4.47	4.10

$\overline{\overline{x}} = 19.247$ $UCL_{\overline{x}} = 21.076$ $LCL_{\overline{x}} = 17.418$ $\sigma = 3.048$ $UCL_s = 4.328$ $LCL_s = 1.768$

Table 4. Control Chart Data -- Study A
(Continued)

Oper.		1	2	3	4	5	6			
N	$\bar{x}$	19.04	18.60	18.88	18.52	18.80	18.20	$\bar{\bar{x}} = 18.607$	$UCL_{\bar{x}} = 20.059$	$LCL_{\bar{x}} = 17.155$
	s	2.67	2.61	2.47	2.69	1.96	2.12	$\sigma = 2.420$	$UCL_s = 3.436$	$LCL_s = 1.404$
P	$\bar{x}$	20.68	20.24	19.00	18.84	19.52	19.96	$\bar{\bar{x}} = 19.707$	$UCL_{\bar{x}} = 21.282$	$LCL_{\bar{x}} = 18.132$
	s	2.95	2.65	2.58	1.93	2.63	3.01	$\sigma = 2.625$	$UCL_s = 3.728$	$LCL_s = 1.522$
Q	$\bar{x}$	16.92	16.24	16.84	17.72	15.92	17.08	$\bar{\bar{x}} = 16.787$	$UCL_{\bar{x}} = 17.978$	$LCL_{\bar{x}} = 15.596$
	s	2.00	1.69	1.95	2.61	1.54	2.12	$\sigma = 1.985$	$UCL_s = 2.819$	$LCL_s = 1.151$
R	$\bar{x}$	16.68	18.20	16.88	16.12	17.04	17.44	$\bar{\bar{x}} = 17.060$	$UCL_{\bar{x}} = 18.672$	$LCL_{\bar{x}} = 15.448$
	s	2.59	3.30	2.96	2.28	2.54	2.45	$\sigma = 2.687$	$UCL_s = 3.816$	$LCL_s = 1.558$
S	$\bar{x}$	20.24	19.28	21.84	20.64	20.96	21.40	$\bar{\bar{x}} = 20.727$	$UCL_{\bar{x}} = 22.629$	$LCL_{\bar{x}} = 18.825$
	s	2.57	2.00	3.82	2.81	3.31	4.55	$\sigma = 3.170$	$UCL_s = 4.501$	$LCL_s = 1.839$
T	$\bar{x}$	19.88	20.56	19.20	19.20	18.20	19.27	$\bar{\bar{x}} = 19.385$	$UCL_{\bar{x}} = 20.924$	$LCL_{\bar{x}} = 17.846$
	s	2.64	3.29	2.25	2.77	1.89	2.12	$\sigma = 2.565$	$UCL_s = 3.642$	$LCL_s = 1.488$

Table 4. Control Chart Data -- Study A
(Continued)

Oper.		1	2	3	4	5	6			
U	$\bar{x}$	22.00	21.26	21.82	21.92	24.32	24.84	$\bar{\bar{x}} = 22.693$	$UCL_{\bar{x}} = 24.979$	$LCL_{\bar{x}} = 20.407$
	s	3.50	2.75	3.75	3.50	4.22	5.14	$\sigma = 3.810$	$UCL_s = 5.410$	$LCL_s = 2.210$

Table 5. Summary of Results of Analysis of Variance
--Study 3-1 Data (Variables Included)--

Operator	F Ratio	d. f.	P	Stable*
B	---(sample size too small)---			
D	1.3	3, 19	.20	
E	0.6	3, 37	.20	
F	---(sample size too small)---			
G	6.0	3, 37	.01	No
H	2.5	7, 58	,04	No
J	0.8	7, 73	.20	
K	5.5	7, 71	.01	No
M	1.5	6, 63	.20	
N	2.5	7, 61	.04	No
P	1.9	7, 65	.12	
Q	1.5	7, 84	.20	
R	0.7	7, 80	.20	
S	4.8	4, 37	.01	No
T	1.3	7, 73	.20	
V	0.3	2, 30	.20	
W	5.1	4, 16	.01	No
X	4.0	7, 68	.01	No
Z	2.2	7, 57	.05	No

*If the F ratio was Significantly large at greater than the 90 per cent level of confidence, the hypothesis of equal means was rejected and instability was concluded. For details on the above calculations, see Friedman (25).

Table 6. Calculated Data for Control Charts

Operator H--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
			(1) Variables Included					
1	7	3:30 PM	16.986	17.339	13.361	1.580	3.133	0.370
2	9	4:20	15.428	17.110	13.590	1.500	2.992	0.546
3	7	5:15	15.450	17.339	13.361	2.542	3.133	0.370
4	8	6:55	15.212	17.216	13.484	1.854	3.062	0.475
5	9	7:35	13.811	17.110	13.590	1.053	2.992	0.546
6	9	8:30	14.661	17.110	13.590	1.110	2.992	0.546
7	6	9:15	15.058	17.497	13.203	1.123	3.238	0.282
8	11	10:35	16.259	16.934	13.766	2.430	2.869	0.651
		$N_n = 66$	$\bar{\bar{X}} = 15.350$		σ	$= 1.760$		
			(2) Variables Excluded					
1	5	3:30	16.580	16.697	13.003	1.641	2.646	0.110
2	8	4:20	15.119	16.311	13.389	1.254	2.398	0.372
3	5	5:15	14.420	16.697	13.003	1.032	2.646	0.110
4	7	6:55	15.271	16.407	13.293	1.994	2.453	0.289
5	5	7:35	13.430	16.697	13.003	1.291	2.646	0.110
6	5	8:30	14.090	16.697	13.003	1.121	2.646	0.110
7	3	9:15	14.500	17.234	12.466	0.606	2.949	0
8	7	10:35	14.900	16.407	13.293	1.151	2.453	0.289
$N_n = 45$				$\bar{\bar{X}} = 14.850$		σ	$= 1.378$	

All times in .01 minutes

Table 7. Calculated Data for Control Charts

Operator K--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	10	3:40 PM	14.815	14.648	12.140	2.016	2.191	0.449
2	10	4:30	12.945	14.648	12.140	1.525	2.191	0.449
3	14	5:20	12.571	14.450	12.338	1.280	2.059	0.568
4	7	7:00	13.379	14.886	11.902	0.961	2.350	0.277
5	11	7:40	13.659	14.582	12.206	1.074	2.152	0.488
6	10	8:35	12.415	14.648	12.140	1.188	2.191	0.449
7	9	9:20	12.856	14.714	12.074	0.870	2.244	0.409
8	8	10:45	15.094	14.793	11.995	1.134	2.297	0.356
	N_n = 79		$\bar{\bar{X}}$ = 13.394			σ = 1.320		
				(2) Variables Excluded				
1	8	3:40 PM	14.812	14.610	11.900	2.219	2.224	0.345
2	9	4:30	12.894	14.533	11.977	1.608	2.173	0.396
3	11	5:20	12.127	14.405	12.105	0.775	2.083	0.473
4	7	7:00	13.379	14.699	11.811	0.961	2.275	0.268
5	7	7:40	13.829	14.699	11.811	1.300	2.275	0.268
6	7	8:35	11.921	14.699	11.811	0.524	2.275	0.268
7	5	9:20	12.530	14.967	11.543	0.670	2.454	0.102
8	7	10:45	14.871	14.699	11.811	1.020	2.275	0.268
	N_n = 61		$\bar{\bar{X}}$ = 13.255			σ = 1.278		

All times in .01 minutes

Table 8. Calculated Data for Control Charts

Operator M--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	9	3:45 PM	16.044	17.805	12.465	2.662	4.539	0.828
2	8	4:35	12.844	17.965	12.305	5.301	4.646	0.721
3	8	5:25	15.119	17.965	12.305	1.464	4.646	0.721
4	10	7:05	15.720	17.671	12.599	3.160	4.432	0.908
5	12	7:45	14.429	17.458	12.812	1.125	4.272	1.041
6	12	8:40	15.421	17.458	12.812	1.501	4.272	1.041
7	..	...	...	...	...	...	...	...
8	12	10:50	15.929	17.458	12.812	2.319	4.272	1.041
	N_n = 71		$\bar{\bar{X}}$ = 15.135			σ = 2.670		
				(2) Variables Excluded				
1	6	3:45 PM	15.292	18.043	11.363	2.638	5.038	0.438
2	7	4:35	12.743	17.797	11.609	5.718	4.874	0.575
3	8	5:25	15.119	17.605	11.801	1.464	4.764	0.739
4	8	7:05	15.638	17.605	11.801	3.548	4.764	0.739
5	9	7:45	13.994	17.441	11.965	0.818	4.655	0.849
6	12	8:40	15.421	17.085	12.321	1.501	4.381	1.068
7	..	...	...	...	...	...	...	...
8	6	10:50	14.242	18.043	11.363	0.794	5.038	0.438
	N_n = 56		$\bar{\bar{X}}$ = 14.703			σ = 2.738		

All times in .01 minutes

Table 9. Calculated Data for Control Charts

Operator X--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	10	3:50 PM	14.275	16.438	12.116	1.509	3.776	0.774
2	12	4:40	14.238	16.256	12.298	2.004	3.640	0.887
3	12	5:30	14.058	16.256	12.298	2.392	3.640	0.887
4	12	7:10	13.862	16.256	12.298	1.324	3.640	0.887
5	11	7:50	14.168	16.325	12.229	2.417	3.708	0.842
6	11	8:45	12.782	16.325	12.229	1.887	3.708	0.842
7	3	9:30	14.583	18.213	10.341	2.006	4.868	0
8	6	11:00	18.400	17.053	11.501	4.650	4.186	0.364
	N_n = 77		$\bar{\bar{X}}$ = 14.277			σ = 2.275		
				(2) Variables Excluded				
1	10	3:50 PM	14.275	15.402	12.176	1.509	2.819	0.577
2	12	4:40	14.238	15.266	12.312	2.004	2.717	0.662
3	11	5:30	13.409	15.317	12.261	0.853	2.768	0.628
4	11	7:10	13.850	15.317	12.261	1.388	2.768	0.628
5	10	7:50	13.800	15.402	12.176	2.199	2.819	0.577
6	11	8:45	12.782	15.317	12.261	1.887	2.768	0.628
7	3	9:30	14.583	16.727	10.851	2.006	3.634	0
8	2	11:00	14.675	17.389	10.189	0.672	3.871	0
	N_n = 70		$\bar{\bar{X}}$ = 13.789			σ = 1.698		

All times in .01 minutes

Table 10. Calculated Data for Control Charts

Operator Z--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	5	3:55 PM	20.10	20.146	14.644	3.784	3.942	0.164
2	7	4:45	18.736	19.715	15.075	2.894	3.654	0.431
3	8	5:35	17.581	19.571	15.219	1.086	3.572	0.554
4	11	7:15	16.673	19.243	15.547	2.308	3.346	0.760
5	9	7:55	17.000	19.448	15.342	1.688	3.490	0.636
6	9	8:50	16.933	19.448	15.342	1.934	3.490	0.636
7	8	9:35	16.638	19.571	15.219	0.624	3.572	0.554
8	8	11:05	17.062	19.571	15.219	1.494	3.572	0.554
	$N_n = 65$		$\bar{\bar{X}} = 17.395$			$\sigma = 2.053$		
				(2) Variables Excluded				
1	4	3:55 PM	18.725	19.602	14.550	2.548	3.385	0
2	6	4:45	17.675	19.130	15.022	0.772	3.099	0.269
3	8	5:35	17.581	18.861	15.291	1.886	2.930	0.455
4	11	7:15	16.673	18.592	15.560	2.308	2.745	0.623
5	7	7:55	16.407	18.979	15.173	1.358	2.998	0.354
6	8	8:50	16.950	18.861	15.291	2.067	2.930	0.455
7	6	9:35	16.425	19.130	15.022	0.488	3.099	0.269
8	8	11:05	17.062	18.861	15.291	1.494	2.930	0.455
	$N_n = 58$		$\bar{\bar{X}} = 17.076$			$\sigma = 1.684$		

All times in .01 minutes

Table 11. Calculated Data for Control Charts

Operator J--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	12	4:00 PM	13.521	14.739	11.913	1.468	2.598	0.633
2	9	4:50	12.628	14.950	11.702	1.136	2.761	0.503
3	11	5:45	13.136	14.788	11.864	1.304	2.647	0.601
4	9	7:20	13.006	14.950	11.702	1.480	2.761	0.503
5	9	8:00	13.306	14.950	11.702	1.460	2.761	0.503
6	12	8:55	13.346	14.739	11.913	1.142	2.598	0.633
7	9	9:40	14.244	14.950	11.702	3.344	2.761	0.503
8	11	11:10	13.373	14.788	11.864	0.766	2.647	0.601
	N_n = 82		$\bar{\bar{X}}$ = 13.326			σ = 1.624		
				(2) Variables Excluded				
1	10	4:00 PM	13.425	14.072	12.018	1.518	1.794	0.368
2	9	4:50	12.628	14.126	11.964	1.136	1.838	0.335
3	10	5:45	12.990	14.072	12.018	1.275	1.794	0.368
4	7	7:20	12.500	14.267	11.823	0.766	1.924	0.227
5	7	8:00	13.014	14.267	11.823	0.661	1.924	0.227
6	12	8:55	13.346	13.985	12.105	1.142	1.730	0.422
7	7	9:40	12.671	14.267	11.823	0.804	1.924	0.227
8	11	11:10	13.373	14.018	12.072	0.766	1.762	0.400
	N_n = 73		$\bar{\bar{X}}$ = 13.045			σ = 1.081		

All times in .01 minutes

Table 12. Calculated Data for Control Charts

Operator S--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\overline{X}$	$UCL_{\overline{X}}$	$LCL_{\overline{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	10	11:55 PM	16.990	18.812	15.704	1.226	2.716	0.556
2	9	12:30	16.728	18.894	15.622	1.324	2.781	0.507
3	11	1:55	16.709	18.730	15.786	2.094	2.667	0.605
4	..	...	...	...	...	...	...	...
5	5	3:30	20.230	19.450	15.066	2.125	3.141	0.131
6	7	4:25	17.064	19.107	15.409	1.265	2.912	0.344
7	..	...	...	...	...	...	...	...
8	..	...	...	...	...	...	...	...
	N_n = 42		$\overline{\overline{X}}$ = 17.258			σ = 1.636		
				(2) Variables Excluded				
1	7	11:55 PM	16.707	17.728	15.294	1.207	1.917	0.226
2	4	12:30	16.650	18.127	14.895	0.750	2.165	0
3	5	1:55	15.750	17.954	15.068	0.924	2.068	0.086
4	..	...	...	...	...	...	...	...
5	..	...	...	...	...	...	...	...
6	6	4:25	16.817	17.825	15.197	1.186	1.982	0.172
7	..	...	...	...	...	...	...	...
8	..	...	...	...	...	...	...	...
	N_n = 22		$\overline{\overline{X}}$ = 16.511			σ = 1.077		

All times in .01 minutes

Table 13. Calculated Data for Control Charts

Operator T--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
(1) Variables Included								
1	8	12:05 AM	16.344	17.286	13.866	1.600	2.807	0.436
2	10	12:35	16.110	17.108	14.044	0.953	2.678	0.548
3	10	2:05	15.725	17.108	14.044	1.296	2.678	0.548
4	10	2:35	15.800	17.108	14.044	2.087	2.678	0.548
5	9	3:35	16.122	17.189	13.963	2.248	2.742	0.500
6	12	4:30	14.821	16.979	14.173	1.066	2.581	0.629
7	10	5:40	15.065	17.108	14.044	1.722	2.678	0.548
8	12	6:15	15.088	16.979	14.173	1.653	2.581	0.629
	N_n = 81		$\bar{\bar{X}}$ = 15.576			σ = 1.613		
(2) Variables Excluded								
1	8	12:05 AM	16.344	16.905	13.773	1.600	2.570	0.399
2	6	12:35	15.967	17.141	13.537	0.940	2.718	0.236
3	10	2:05	15.725	16.742	13.936	1.296	2.452	0.502
4	9	2:35	15.444	16.816	13.862	1.864	2.511	0.458
5	7	3:35	15.207	17.008	13.670	1.324	2.629	0.310
6	10	4:30	14.700	16.742	13.936	1.109	2.452	0.502
7	9	5:40	14.783	16.816	13.862	1.563	2.511	0.458
8	10	6:15	14.925	16.742	13.936	1.722	2.452	0.502
	N_n = 69		$\bar{\bar{X}}$ = 15.339			σ = 1.477		

All times in .01 minutes

Table 14. Calculated Data for Control Charts

Operator P--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{\bar{X}}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	8	12:10 AM	15.194	15.761	12.331	1.943	2.815	0.437
2	10	12:40	13.845	15.583	12.509	0.827	2.686	0.550
3	11	2:07	13.609	15.502	12.590	1.518	2.637	0.559
4	4	2:40	15.200	16.473	11.619	0.701	3.252	0
5	11	3:40	13.923	15.502	12.590	1.575	2.637	0.559
6	6	4:35	13.400	16.020	12.072	1.603	2.977	0.259
7	10	5:45	14.875	15.583	12.509	2.292	2.686	0.550
8	13	6:20	13.277	15.389	12.703	1.532	2.556	0.680
	N_n = 73		$\bar{\bar{X}}$ = 14.046		σ = 1.618			
				(2) Variables Excluded				
1	2	12:10 AM	15.900	16.864	9.880	2.334	3.755	0
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	..	...	...	...	...	...	...	...
5	..	...	...	...	...	...	...	...
6	..	...	...	...	...	...	...	...
7	..	...	...	...	...	...	...	...
8	9	6:20	12.811	15.019	11.725	1.540	2.800	0.511
	N_n = 11		$\bar{\bar{X}}$ = 13.372		σ = 1.647			

All times in.01 minutes

Table 15. Calculated Data for Control Charts

Operator R--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	10	12:15 AM	13.115	13.992	11.616	1.723	2.075	0.425
2	9	12:45	13.089	14.054	11.554	1.167	2.125	0.388
3	12	2:10	12.788	13.892	11.716	0.740	2.000	0.488
4	6	2:45	13.300	14.329	11.279	1.034	2.300	0.200
5	12	3:45	12.675	13.892	11.716	1.090	2.000	0.488
6	13	4:40	12.942	13.842	11.766	1.452	1.975	0.525
7	13	5:50	12.273	13.842	11.766	1.062	1.975	0.525
8	13	6:25	12.662	13.842	11.766	1.418	1.975	0.525
	$N_n = 88$		$\bar{\bar{X}} = 12.804$			$\sigma = 1.250$		
				(2) Variables Excluded				
1	7	12:15 AM	12.664	13.569	11.301	1.396	1.787	0.211
2	7	12:45	13.271	13.569	11.301	1.280	1.787	0.211
3	7	2:10	12.714	13.569	11.301	0.857	1.787	0.211
4	3	2:45	12.450	14.172	10.698	0.444	2.149	0
5	8	3:45	12.231	13.499	11.371	0.780	1.747	0.271
6	7	4:40	12.557	13.569	11.301	1.140	1.787	0.211
7	8	5:50	11.769	13.499	11.371	0.764	1.747	0.271
8	9	6:25	12.072	13.439	11.431	1.364	1.707	0.311
	$N_n = 56$		$\bar{\bar{X}} = 12.435$			$\sigma = 1.004$		

All times in .01 minutes

Table 16. Calculated Data for Control Charts

Operator Q--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Includes				
1	10	12:20 AM	13.760	14.483	12.163	0.858	2.027	0.415
2	11	12:55	14.059	14.422	12.224	1.760	1.990	0.452
3	13	2:20	13.258	14.336	12.310	1.252	1.929	0.513
4	10	2:50	13.555	14.483	12.163	1.065	2.027	0.415
5	12	3:50	13.271	14.385	12.261	1.058	1.954	0.476
6	11	5:25	13.191	14.422	12.224	1.274	1.990	0.452
7	13	5:55	13.019	14.336	12.310	1.296	1.929	0.513
8	12	6:27	12.662	14.385	12.261	0.950	1.954	0.476
	N_n = 92		$\bar{\bar{X}}$ = 13.323		σ = 1.221			
				(2) Variables Excluded				
1	10	12:20 AM	13.760	14.038	12.158	0.858	1.643	0.337
2	8	12:55	13.338	14.147	12.049	0.787	1.723	0.267
3	11	2:20	13.068	13.989	12.207	1.268	1.614	0.366
4	3	2:50	12.900	14.811	13.385	0.328	2.119	0
5	11	3:50	13.305	13.989	12.207	1.103	1.614	0.366
6	11	5:25	13.191	13.989	12.207	1.274	1.614	0.366
7	10	5:55	12.590	14.038	12.158	0.515	1.643	0.337
8	10	6:27	12.525	14.038	12.158	0.856	1.643	0.337
	N_n = 74		$\bar{\bar{X}}$ = 13.098		σ = 0.990			

All times in .01 minutes

Table 17. Calculated Data for Control Charts

Operator N--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	5	12:25 AM	18.120	18.958	13.738	3.317	3.740	0.156
2	8	1:00	15.194	18.413	14.283	0.770	3.390	0.526
3	11	2:25	16.373	18.101	14.595	2.351	3.175	0.721
4	7	2:55	16.800	18.549	14.147	0.908	3.467	0.409
5	9	3:55	14.450	18.296	14.400	2.210	3.312	0.604
6	10	5:20	16.700	18.199	14.497	1.766	3.234	0.662
7	9	6:05	16.928	18.296	14.400	1.955	3.312	0.604
8	10	6:35	16.880	18.199	14.497	1.680	3.234	0.662
	N_n = 69		$\bar{\bar{X}}$ = 16.348			σ = 1.948		
				(2) Variables Excluded				
1	3	12:25 AM	15.850	18.067	13.593	0.889	2.767	0
2	5	1:00	14.860	17.563	14.097	0.531	2.483	0.104
3	6	2:25	15.475	17.407	14.253	0.844	2.379	0.207
4	4	2:55	16.900	17.770	13.890	0.765	2.599	0
5	5	3:55	13.900	17.563	14.097	1.186	2.483	0.104
6	7	5:20	15.843	17.291	13.369	1.210	2.302	0.272
7	4	6:05	16.450	17.770	13.890	1.905	2.599	0
8	9	6:35	16.906	17.123	14.537	1.775	2.198	0.401
	N_n = 43		$\bar{\bar{X}}$ = 15.830			σ = 1.293		

All times in .01 minutes

Table 18. Calculated Data for Control Charts

Operator W--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{x}}$	$LCL_{\bar{x}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	3	11:05 AM	24.483	29.074	20.680	4.850	5.192	0
4	5	11:40	23.040	28.128	21.626	1.226	4.658	0.199
5	6	1:05	24.000	27.837	21.917	0.787	4.464	0.388
6	3	2:10	26.950	29.074	20.680	0.529	5.192	0
7	5	2:50	26.760	28.128	21.626	3.294	4.658	0.199
8	..	...	...	...	...	...	...	...
	N_n = 22		$\bar{\bar{X}}$ = 24.877			σ = 2.426		
				(2) Variables Excluded				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	3	11:05 AM	24.483	28.635	20.985	4.850	4.732	0
4	4	11:40	22.888	28.126	21.494	1.360	4.444	0
5	6	1:05	24.000	27.507	22.113	0.787	4.068	0.354
6	2	2:10	27.050	29.497	20.123	0.707	5.041	0
7	4	2:50	25.512	28.126	21.494	2.022	4.444	0
8	..	...	...	...	...	...	...	...
	N_n = 19		$\bar{\bar{X}}$ = 24.810			σ = 2.211		

All times in .01 minutes

Table 19. Calculated Data for Control Charts

Operator G--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
			(1) Variables Included					
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	10	11:35 AM	13.930	16.278	13.024	0.879	2.844	0.582
5	11	1:15	13.614	16.193	13.109	1.456	2.792	0.634
6	11	2:15	14.718	16.193	13.109	1.632	2.792	0.634
7	9	2:55	16.644	16.364	12.938	2.593	2.912	0.531
8	..	...	...	...	...	...	...	...
	$N_n = 41$		$\bar{\bar{X}} = 14.651$			$\sigma = 1.713$		
			(2) Variables Excluded					
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	8	11:35 AM	13.825	16.167	12.521	0.836	2.993	0.464
5	10	1:15	13.270	15.978	12.710	0.955	2.855	0.585
6	10	2:15	14.555	15.978	12.710	1.623	2.855	0.585
7	6	2:55	16.467	16.442	12.246	3.224	3.165	0.275
8	..	...	...	...	...	...	...	...
	$N_n = 34$		$\bar{\bar{X}} = 14.344$			$\sigma = 1.720$		

All times in .01 minutes

Table 20. Calculated Data for Control Charts

Operator D--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
			(1) Variables Included					
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...
4	5	11:10 AM	16.040	17.758	13.596	2.496	2.982	0.124
5	6	12:35	16.383	17.572	13.782	1.590	2.858	0.248
6	6	1:25	15.633	17.572	13.782	0.905	2.858	0.248
7	6	2:20	14.725	17.572	13.782	0.913	2.858	0.248
8	..	...	...	...	...	...	...	...
	N_n = 23		$\bar{\bar{X}}$ = 15.677			σ = 1.553		
			(2) Variables Excluded					
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	4	11:10 AM	16.162	17.791	13.131	2.865	3.122	0
5	4	12:35	15.625	17.791	13.131	1.378	3.122	0
6	6	1:25	15.633	17.356	13.566	0.905	2.858	0.248
7	6	2:20	14.725	17.356	13.566	0.913	2.858	0.248
8	..	...	...	...	...	...	...	...
	N_n = 20		$\bar{\bar{X}}$ = 15.461			σ = 1.553		

All times in .01 minutes

Table 21. Calculated Data for Control Charts

Operator E--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{x}}$	$LCL_{\bar{x}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	12	11:15 AM	14.521	16.116	12.772	1.878	3.075	0.750
5	11	12:40	14.832	16.174	12.714	2.446	3.133	0.711
6	11	1:35	14.214	16.174	12.714	1.729	3.133	0.711
7	8	2:25	14.125	16.481	12.407	1.300	3.344	0.519
8	..	...	...	...	...	...	...	...
	N_n = 42		$\bar{\bar{X}}$ = 14.444		σ = 1.922			
				(2) Variables Excluded				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	11	11:15 AM	14.536	16.332	12.786	1.969	3.211	0.729
5	8	12:40	15.294	16.647	12.471	2.654	3.428	0.532
6	11	1:35	14.214	16.332	12.786	1.729	3.211	0.729
7	7	2:25	14.300	16.785	12.333	1.298	3.507	0.414
8	..	...	...	...	...	...	...	...
	N_n = 37		$\bar{\bar{X}}$ = 14.559		σ = 1.970			

All times in .01 minutes

Table 22. Calculated Data for Control Charts

Operator V--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	12	11:20 AM	14.308	15.873	13.129	1.641	2.523	0.615
5	..	...	...	...	...	...	...	...
6	11	1:40	14.414	15.920	13.082	1.559	2.571	0.583
7	10	2:35	14.830	15.999	13.003	1.515	2.618	0.536
8	..	...	...	...	...	...	...	...
	N_n = 33		$\bar{\bar{X}}$ = 14.501		σ	= 1.577		
				(2) Variables Excluded				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...
4	12	11:20 AM	14.308	15.872	12.980	1.641	2.659	0.648
5	..	...	...	...	...	...	...	...
6	10	1:40	14.395	16.005	12.847	1.642	2.759	0.565
7	7	2:35	14.664	16.304	12.548	1.727	2.958	0.349
8	..	...	...	...	...	...	...	...
	N_n = 29		$\bar{\bar{X}}$ = 14.426		σ	= 1.662		

All times in .01 minutes

Table 23. Calculated Data for Control Charts

Operator B--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{x}}$	$LCL_{\bar{x}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	..	...	...	...	...	...	...	...
5	..	...	...	...	...	...	...	...
6	..	...	...	...	...	...	...	...
7	8	2:40 PM	15.188	16.948	13.428	1.660	2.888	0.448
8	..	...	...	...	...	...	...	...
	$N_n = 8$		$\bar{\bar{X}} = 15.188$			$\sigma = 1.660$		
				(2) Variables Excluded				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	..	...	...	...	...	...	...	...
5	..	...	...	...	...	...	...	...
6	..	...	...	...	...	...	...	...
7	4	2:40 PM	15.362	18.629	12.095	2.178	3.877	0
8	..	...	...	...	...	...	...	...
	$N_n = 4$		$\bar{\bar{X}} = 15.362$			$\sigma = 2.178$		

All times in .01 minutes

Table 24. Calculated Data for Control Charts

Operator F--Shot Means, Standard Deviations, and Control Limits

Shot	n	Time	$\bar{X}$	$UCL_{\bar{X}}$	$LCL_{\bar{X}}$	s	UCL_s	LCL_s
				(1) Variables Included				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	..	...	...	...	...	...	...	...
5	4	1:00 PM	14.950	19.660	14.110	1.861	3.718	0
6	..	...	...	...	...	...	...	...
7	4	2:50	18.838	19.660	14.110	1.840	3.718	0
8	..	...	...	...	...	...	...	...
	N_n = 8		$\bar{\bar{X}}$ = 16.885			σ = 1.850		
				(2) Variables Excluded				
1	..	...	...	...	...	...	...	...
2	..	...	...	...	...	...	...	...
3	..	...	...	...	...	...	...	...
4	..	...	...	...	...	...	...	...
5	4	1:00 PM	14.950	19.581	13.485	1.861	4.084	0
6	..	...	...	...	...	...	...	...
7	2	2:50	19.700	20.841	12.225	2.475	4.633	0
8	..	...	...	...	...	...	...	...
	N_n = 6		$\bar{\bar{X}}$ = 16.533			σ = 2.032		

All times in .01 minutes

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