STATISTICAL QUALITY CONTROL TECHNIQUES IN THE TEXTILE INDUSTRY

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Statistical Techniques Used in the Evaluation of Product Quality

General. Wherever a test of product quality is performed, it is necessary to evaluate the results in terms of two basic measures; (1) a measure of **central tendency**, such as the arithmetical average and (2) a measure of **variability**, such as the range, the standard deviation, or a coefficient of variation. These are the most widely used measures, and the ones best suitable for textile quality control.

Arithmetical Average. The determination of the arithmetical average or simply "average" is a fundamental procedure in practically all cases where a series of tests have been performed. As an illustration, let us assume that the breaking strength in pounds has been determined on each of six bobbins of yarn, with the test results and computation of the average shown in Table I.

TABLE I

COMPUTATION OF ARITHMETICAL AVERAGE

Test No.	Breaking Strength, Lb.
1	49
2	45
3	47
4	46
5	43
6	46
Total	276

Number of tests $N = 6$
Arithmetical average, $\bar{X} = 276/6 = 46$ lb.

In this example, the total of 276 lb. was divided by the number of tests, 6, to produce the arithmetical average of 46 lb. Symbolically, the arithmetical average is usually shown by $\bar{X}$.

Range. Variability is measured most simply by means of the range, which is denoted by R and represents the difference between the highest and lowest value in a set of tests. For example in Table I, the highest value is 49 lb. and the lowest value is 43 lb. with a difference of 6 lb. representing the range. The range, R, may also be expressed as a percentage of the arithmetical average, using the formula:

$$R\% = (R \times 100)/\bar{X} \tag{1}$$

For the illustrative example above,

$$R\% = (6 \times 100)/46 = 13 \tag{2}$$

Colloquial terms sometimes used in place of range and per cent range are "maximum variation" and "maximum variation per cent."

The range is a simple measure of variability, but it is deficient in that it utilizes only two values in a set of tests, the highest and lowest and ignores all intermediate data. This is equivalent to "throwing away" data in evaluating variability. A measure which does not entail this drawback is the standard deviation.

Standard Deviation. The standard deviation is computed in the manner shown in Table II. This uses the previously shown yarn breaking strengths data with two additional columns. The first column headed Deviation from average shows how each individual breaking strength test differed from the average of 46 lbs. Thus, in the first line 49 lb. is 3 lb. greater than the average 46, thereby representing a deviation of +3 lb. Test No. 2 with 45 lb. is 1 lb. below 46 thereby representing a deviation of — 1 lb. When all these calculations are properly completed, the plus and minus values will always balance out to zero. The deviations themselves are therefore not suitable as a measure of variability. However, this problem can be overcome by squaring the deviations, as shown in the last column in the illustration. Thus $3 \times 3 = 9$ for the first line, $-1 \times -1 = +1$, for the second line, and so on, for all six test values. The total of the squared deviations is 20 lb., which upon dividing by the number of tests, 6, produces an average squared deviation of 3.3 lb. In order to compensate for the fact that the individual deviations were squared, the square root is taken next, producing the standard deviation of 1.82 lb. The symbol generally used for the standard deviation is the Greek letter sign σ. The standard deviation serves as an index of variability; the lower the value, the less is the variability found in the test data.

Coefficient of Variation. When the standard deviation is expressed as a percentage of the arithmetical average, it is referred to as the "coefficient of variation," or more briefly "variation coefficient," with the symbol V.

$$V = \frac{\text{Standard Deviation}}{\text{Average}} \times 100 \qquad (3)$$

For the example in Table II, with a standard deviation of 1.82 lb. and an average of 46 lb., we have:

$$V = \frac{1.82 \text{ lb.}}{46 \text{ lb.}} \times 100 = 3.96\% \qquad (4)$$

The advantage of the variation coefficient is that it expresses variation as a relative figure of per cent, whereas the standard deviation is expressed in absolute units, such as pound of breaking strength, degrees of temperature, and other similar values, which may not be so readily comparable as percentages.

This is illustrated by the example in Table III. A mill processing man-made fibers on the cotton system tried two different drawing systems. System A yielded sliver weighing 50 grains and system B yielded 60 grains. By merely comparing the standard deviations and noting the lower value of σ for A, it would be concluded that system A yielded less variability. The proper method, however, is to compare the variability in relation to the average weights. This is done by expressing the results in terms of variation coefficients, % V. The resulting value under both systems is 2.0% indicating that there was no real improvement in variability after the difference in sliver weight was considered.

For these and other practical reasons to be presented, the variation coefficient has become a favorite measure of variability in the modern textile mill.

Frequency Distribution. Frequency distributions are used in evaluating quality obtained from a large number of test data. An example of a frequency distribution for breaking strengths of yarn from 126 cones selected randomly from the cone winding room as shown in figure I yielded an average breaking strength of 46 lbs.

The standard deviation and variation coefficient can also be found from this distribution, as illustrated in Table IV This table uses conventional statistical symbols: X is the individual value, x, the deviation of an individual X from the average $\bar{X}$, f, the frequency, N = total number of X's, and Σ denotes "sum of". An example of the practical value of frequency distributions in evaluating quality in the textile mill is given in Fig. 2.

Short-Cut Method of Estimating Variation Coefficients. Since in routine quality control it is often considered too tedious to compute variation coefficients as shown in Table IV a short-cut method of estimating may be employed, utilizing a set of ranges obtained by random samplings from the distributions. In particular, the average range is obtained, which is the average of the set of sample ranges. This average range, multiplied by the appropriate conversion factor from Table V, yields standard deviation. Where the average range is expressed as a per cent of the distribution average, the conversion factor yields coefficient of variation. Illustrative examples of the use of the average range are given under measurement of Within, Between and Overall Variation.

In practical textile work, it is usually permissible to use the simpler method of ranges as an approximation to the more accurate long method of calculations. However, from 24 to 48 ranges are usually required in obtaining the average range, if the estimated variation coefficient is to agree relatively close with the value obtained by the long method.

Analysis of Processing Variation for Various Conditions of Blending and Drafting

In staple fiber processing, various combinations of blending by doublings and attenuation by drafting are possible. In order to evaluate quality variations under these varying conditions and to trace the flow of variations from process to process, a unified system for evaluation is needed. With such a technique, it is possible to discover and correct sources of excessive variation wherever they occur, thus enhancing yarn and fabric quality.

Composition of Variations. Usually, the total or over-all variation in a processing department consists of two elements: within-machine variation and between-machine variation. With in-machine variation represents differences in stock weight from the various deliveries with a machine, whereas between-machine variation represents differences in the average level of stock weight among the machines within a department. Together, within-machine and between-machine variation produce departmental over-all variation, in the manner illustrated in Fig. 3. Since in textile processing, usually several machines from a given department feed one machine in the subsequent department, as illustrated in Fig. 4, the over-all variation in one department, becomes the source of the within-machine variation in the next department. In this example, the over-all variation in finishing drawing, with several drawing frames feeding one roving frame, is the input variation into the within-machine element of roving variation.

Measurement of Within, Between and Over-all Variation. Within-machine and departmental over-all variation are determined quickly and simply by means of average ranges, leading to variation coefficients, the basic method of finding variation coefficients has already been demonstrated. This can generally be performed on a mill's existing sizing data, cumulated over a period of 2-3 months. It is thus a simple and inexpressive tool for periodic determination of elements of variations, within-machines and departmental over-all. From experience, the tentative standards for "good", "average," and "poor" performance for mills processing fiber on the cotton system have been developed. Table VI. Between-machine variation is best determined indirectly, from the relationship depicted in Figure 5.

For practical purposes, only the within-machine and over-allvariation coefficients are needed in a quality control program. If the between-machine variation is excessive, this will become evident by an under excess of over-all variation over within-machine variation, without need to compute the actual value of the between-machine variation coefficients.

Routine Control of Variations. Routine evaluation of variations, from process to process, leading to corrective action where necessary, is based on the principles shown in convenient summary form in Table VII. It may be seen that: (1) the within-machine variation of a process is affected primarily by the over-all variation of the preceding process, and (2) excessively high over-all variation with low within-machine variation at any processing stage, indicates undue difference in between machine levels.

Control Testing for Product Quality

Control Requirements Routine control of product quality levels, from incoming stock through finished product, usually involves three major phases: (1) Essential tests for routine performance must be selected: (2) the proper amount of testing must be determined, so that requisite quality assurance can be obtained with a relative minimum testing cost; and (3) control charts or other tools must be provided, which will facilitate constant supervision over quality levels.

Selection of Tests. Selection of the proper tests to be used for routine control purposes is generally a technical decision, depending upon individual mill requirements. The typical laboratory testing program in Table VIII shows the test generally used for a good program in the average staple fiber processing mill. In addition to types of test in each department. The table also shows recommended testing frequencies based on the number of machines in each department. An estimate of the testing hours per week, required to fulfill the program, is included for each test.

Amount of Testing. The proper number of tests to use can be determined from statistical formula, based upon three factors: (1) the variability present in the processing, as measured in terms of the variation coefficient, %V, (2) the allowable sampling error, %E, or tolerance, which can be permitted for the particular item tested and (3) the sampling risk that can be permitted, that the sample average may, by chance, give an erroneous picture of the production process or lot as a whole.

For most practical purposes, the mill can determine the requisite number of tests required by the use of the formula:

$$N = (t \times V)^2/E^2 \qquad (5)$$

where N, is the number of tests requried; V = variation coefficient in per cent; E is the allowable sampling error; and t is a probability factor obtained from widely published tables of areas under the normal curve. Ready-made tables are also available for rapidly determining the number of tests required for a given set of conditions.

Control Charts. Control charts provide a convenient means for constant supervision over product quality. A typical set of control charts for sizing tests in a cut staple mill is shown in Fig. 6. Test results were plotted daily. It may be noted that on the seventh day the sliver weight exceeded the upper limit, indicating that a corrective gear change should be made. In this particular instance; however, management delayed the decision, until a second out-of-control point occured on the twelfth day. By that time, however, of-standard sizing had been observed to carry out into roving and yarn, as indicated by the control charts. This demonstrates that off-standard quality can be minimized by taking corrective action as soon as an out-of-control point occurs. Moreover, by watching trends of test results in the direction of either the upper or lower control limit, it is often possible to make corrective processing adjustments before an off-standard product has been produced.

Once the proper amount of testing has been determined, as shown in the preceding section, control limits may be established readily. They are drawn on in the chart at a level equal to the process average $\pm$ %E, where E denotes the allowable sampling error or tolerance, as previously defined.

Control charts emphasizes the experience that "one cannot test quality into a product, but that quality must be spun into the yarn woven into the fabric".

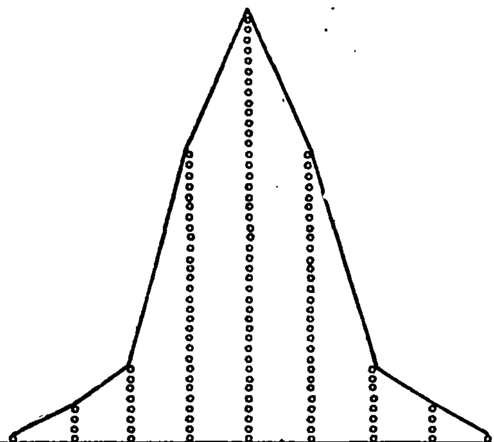
REFERENCES:

N. L. Enrick — "Quality Control Through Statistical Methods" Rayon Publishing Corp., 1954.

Grover's — "Handbook of Quality Control and Testing Procedures in the Textile Industry"

Brearkt and Cox — "An Outline of Statistical Methods for use in the Textile Industry"

FREQUENCY DISTRIBUTION



BREAKS IN LB.	42	43	44	45	46	47	48	49	50	TOTAL
FREQUENCY	1	4	8	29	42	29	8	4	1	126
FREQUENCY X BREAKS	42	172	352	1305	1932	1363	364	196	50	5796

FIG. 1. FREQUENCY DISTRIBUTION OF YARN SKEIN BREAKS.

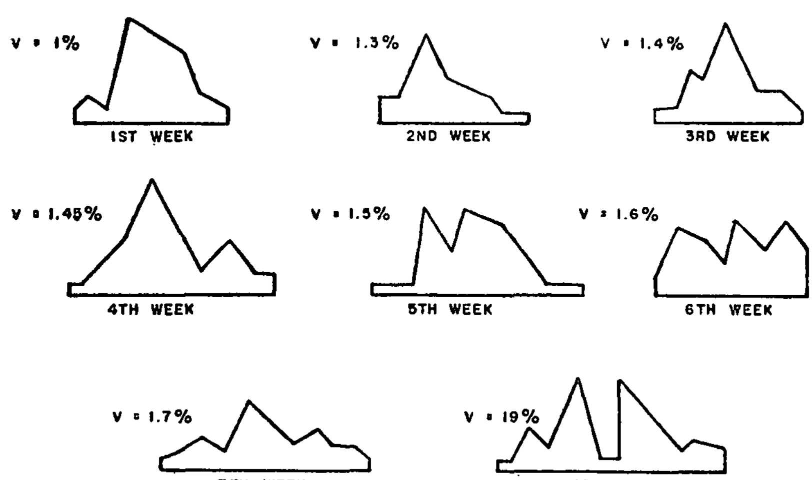
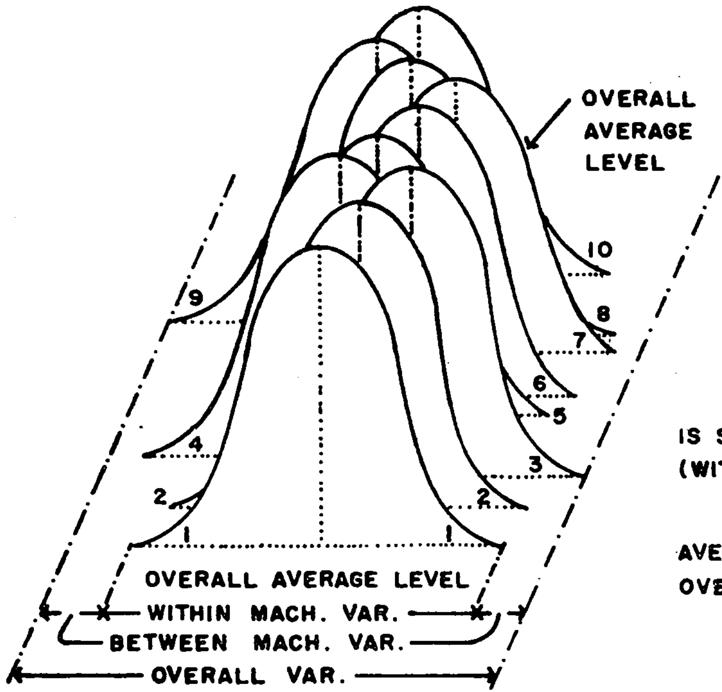
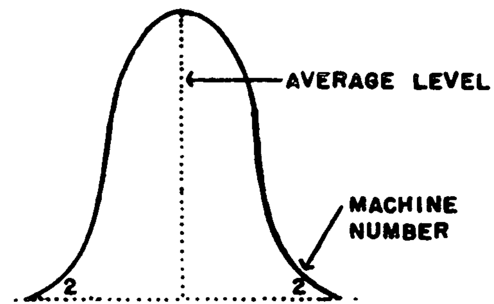


FIG. 2. PICKER LAP DISTRIBUTION CHANGES DURING 8 WEEKS. THE DATA REPRESENT PICKER LAP METER READINGS FOR ONE PICKER. IT IS SHOWN HOW VARIATION COEFFICIENT, V, INCREASED EACH WEEK. AFTER THE 8TH WEEK THE PICKER WAS SCOURED AND READJUSTED, WHICH BROUGHT V BACK TO 1%.

PROCESS VARIATION IS COMPOSED OF TWO MAJOR PARTS — WITHIN-MACHINE VARIATION AND BETWEEN MACHINE VARIATION



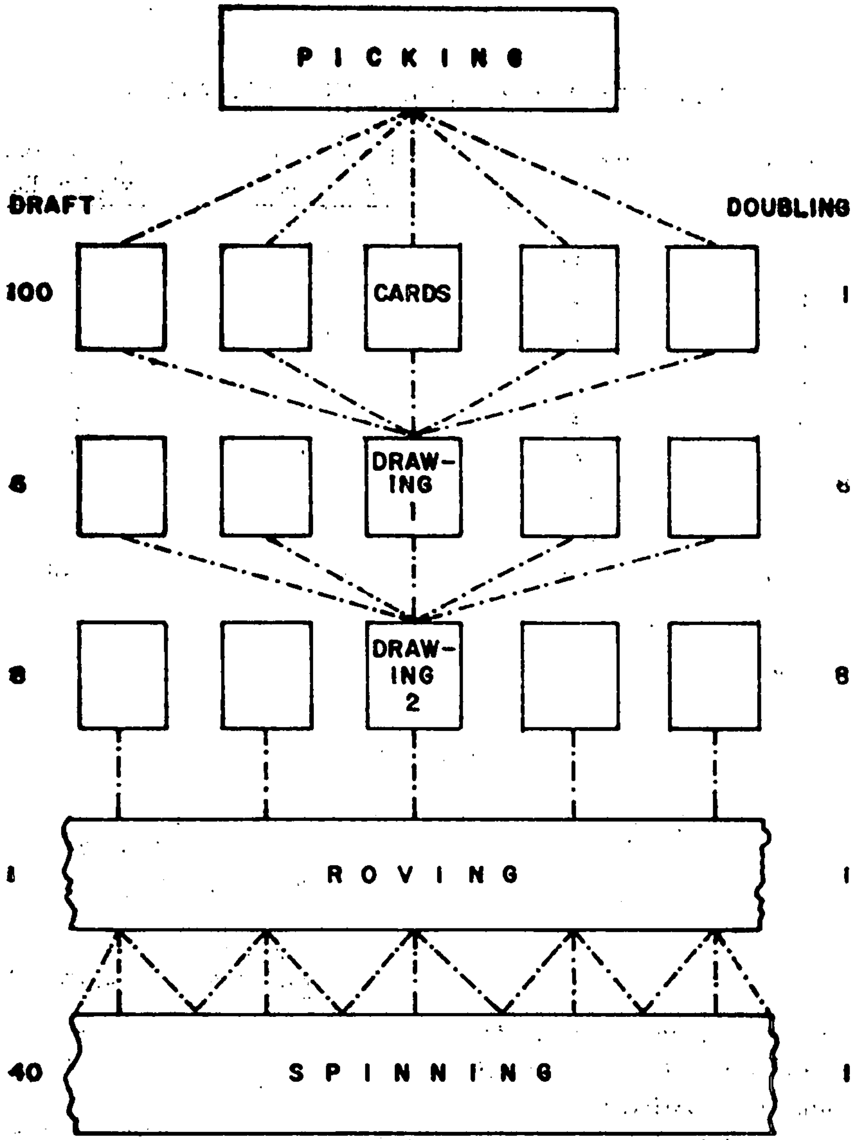


CURVE REPRESENTING PATTERN OF VARIATION

IN THE DIAGRAM TO THE LEFT, EACH MACHINE IS SHOWN TO HAVE THE SAME PATTERN OF VARIATION (WITHIN-MACHINE VARIATION).

HOWEVER, DUE TO DIFFERENCES IN INDIVIDUAL AVERAGE LEVELS BETWEEN THE MACHINES, THE OVERALL VARIATION IS INCREASED.

FIG. 3. PROCESS IS COMPOSED OF TWO MAJOR PARTS, WITHIN-MACHINE VARIATION AND BETWEEN-MACHINE VARIATION.



TOTAL DOUBLINGS = 6 X 8 = 48

TOTAL DRAFT = 100 X 6 X 8 X 5 X 40 = 960,000

FIG. 4. (ABOVE). COTTON AND AMERICAN SYSTEM YARN MILL FLOW CHART.

TABLE II

COMPUTATION OF STANDARD DEVIATION

Test No	Breaking strength lb.	Deviation from Average, lb.	Squared Deviation, lb.
1	49	+3	9
2	45	—1	1
3	47	+1	1
4	46	0	0
5	43	—3	9
6	46	0	0
Totals	276	0	20
Averages	46	——	3.3

Standard deviation, $\sigma = \sqrt{3.3 \text{ lb.}} = 1.82$ lb.

TABLE III

COMPARISON OF STANDARD DEVIATION AND COEFFICIENT OF VARIATION FOR TWO DRAWING SLIVER PROCESSING SYSTEMS IN A MILL

	Drawing System A	Drawing System B
Average of grain weight produced	50	60
Standard deviation, of grain weight	1.0	1.2
Formula for variation coefficient, %V	(1.0/50) × 100	(1.2/60) × 100
Coefficient of Variation, %V	2.0	2.0

TABLE IV

COMPUTATION OF VARIATION COEFFICIENT FOR YARN STRENGTH DISTRIBUTION FROM FIGURE I.

Pounds strength, X	Frequency, f	Frequency X lbs., fX	Deviation from ave., x	(Deviation)^2 x^2	Frequency X (dev)^2 fx^2
42	1	42	4	16	16
43	4	172	3	9	36
44	8	352	2	4	32
45	29	1305	1	1	29
46	42	1932	0	0	0
47	29	1363	1	1	29
48	8	384	2	4	32
49	4	196	3	9	36
50	1	50	4	16	16
—	126	5796	0	—	226

Arithmetical average, $\bar{X} = \frac{\sum fX}{N} = \frac{5796}{126} = 46$

Standard deviation, $\sigma = \sqrt{(\Sigma fx^2)/N} = \sqrt{\frac{226}{126}} = 1.34$

Variation coefficient, $V = \sigma/\bar{X} = 1.34/46 = 2.9\%$

TABLE V

FACTORS FOR CONVERTING AVERAGE RANGE[a] TO STANDARD DEVIATION AND COEFFICIENT OF VARIATION

If sample consist of the following numbers of units, N	Then to obtain standard deviation multiply average range by:
2	0.89
3	0.59
4	0.49
5	0.43
6	0.39
7	0.37
8	0.35
10	0.32
12	0.31
14	0.29
15	0.29
16	0.28
18	0.27
20	0.27
22	0.26
24	0.26
25	0.25

[a]When, in place of average range, the average range in per cent is used, the conversion factor gives variation coefficient.

TABLE VI

STANDARDS FOR SIZE VARIATION OF CUT-STAPLE FIBERS
(Based on analysis of actual mill data)

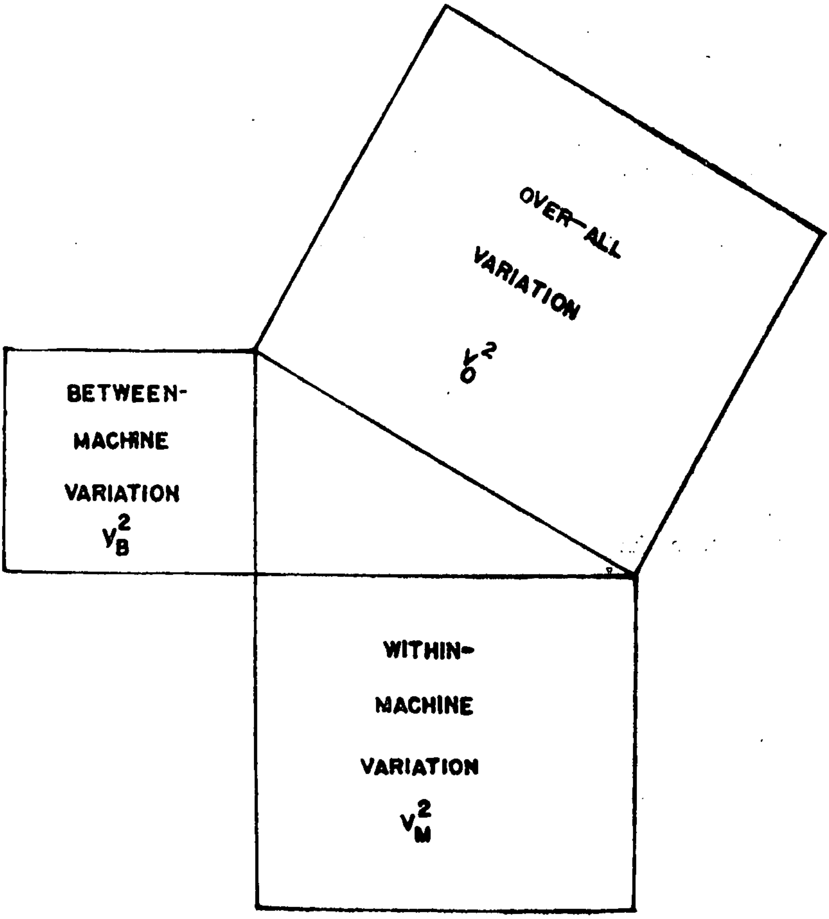
		Variation coefficient, %		
Process	Variation	Low	Average	High
Cards	Within-machine	2.8	3.5	4.3
	Over-all	3.9	5.2	6.3
Drawing I	Within-machine	1.8	2.3	2.8
	Over-all	2.0	2.5	3.1
Drawing II	Within-machine	1.0	1.3	1.6
	Over-all	1.2	1.6	2.0
Slubbers	Within-machine	1.4	1.9	2.4
	Over-all	1.6	2.1	2.8
Spinning	Within-machine	2.1	2.6	3.5
	Over-all	2.3	2.8	3.8

TABLE VII

PROCESS-TO-PROCESS VARIATIONS EVALUATION CHART

Conditions found at a given process	Interpretation of that condition
1. Vm[a] is approximately equal to Vop.	Variation is under good control.
2. Vm is greater than Vop.	Caused by mechanical differences within machines, such as trumpets or roll weights.
3. Vm is smaller than Vop, or Vo is smaller than Vm.	Impossible physically. Check for errors in testing or calculating, non-homogeneous data, or inadequate amount of sampling.
4. Vo is considerably greater than Vm.	Variation is being introduced due to excessive differences in the average levels between machines, such as wrong draft gears or tension gears in the drafting train.

av = Variation coefficient &, m = within-machine, o = over-all, p = in prior process. Where doublings occur, all Vop values should be divided by the value $\sqrt{\text{Doublings}}$ to allow for this effect.



$$V_O^2 = V_B^2 + V_M^2$$

$$V_O = V_B^2 + V_M^2$$

FIG. 5. HOW VARIATION IS BUILT UP.

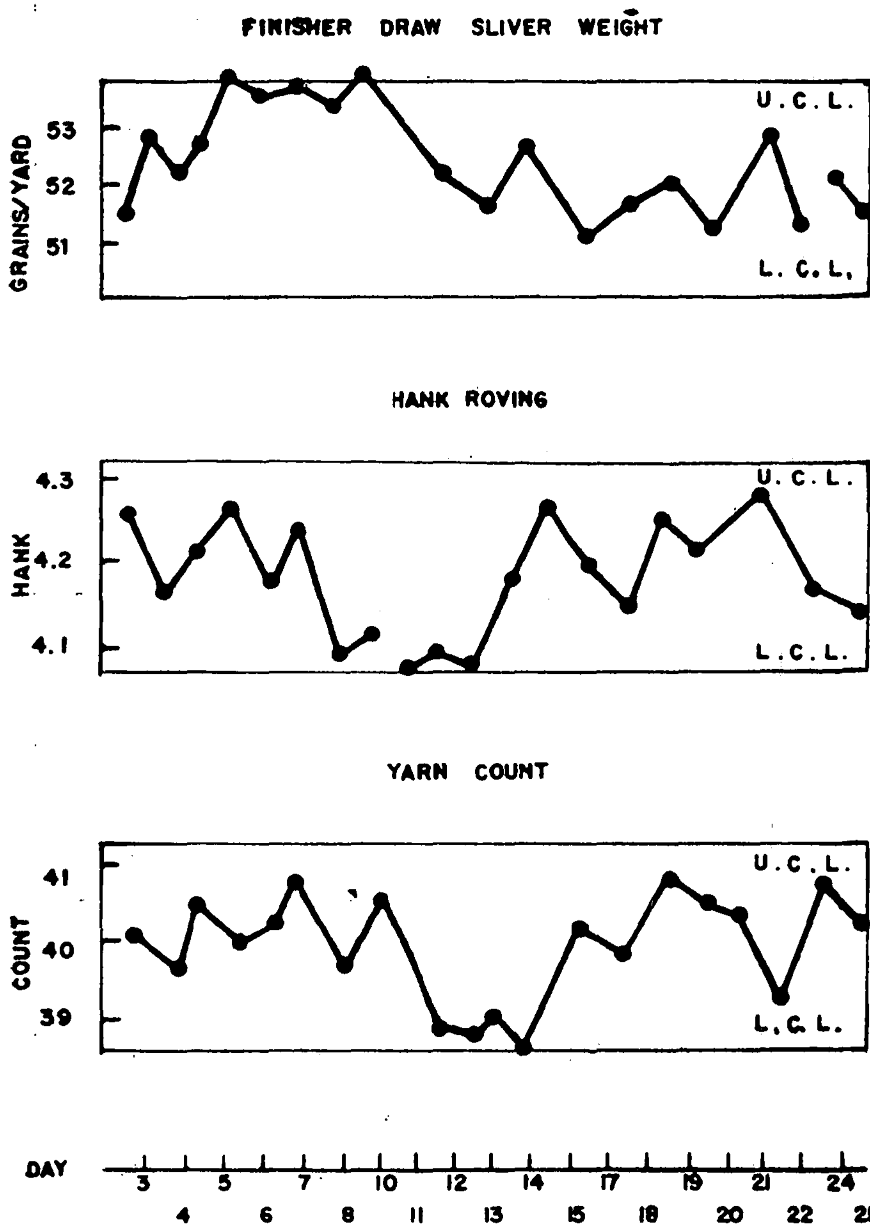


FIG 6 CONTROL CHARTS WITH UPPER CONTROL LIMITS (U.C L) AND LOWER CONTROL LIMITS (L.C.L.) AID IN CENTRALIZED SURVEILLANCE OF QUALITY.

TABLE VIII

TYPICAL LABORATORY TESTING PROGRAM

Test name	Pickers 4	Cards 130	Breakers 14	Finishers 14	Interdrafts 15	Spinning frames 200	Yarn prep.	Looms 1200	Cloth Room
Sizing									
Frequency	Weekly	Weekly	Weekly	Daily	Daily	Daily	— —	— —	Weekly
Number	8 laps	10 cards	1 del/fr.	1 del/fr.	7 Frs.	4 Frs.	— —	— —	All styles
Hr./wk.	0.5	0.5	1.0	5.0	6.0	3.0	— —	— —	5.0
Speeds									
Frequency	5 Wks.	Weekly	5 Wks.	5 Wks.	5 Wks.	5 Wks.	5 Wks.	Weekly	5 Wks.
Number	4 Pickers	10 cards	14 Frs.	14 Frs.	15 Frs.	200 Frs.	— —	120 looms	— —
Hr./wk.	0.1	0.5	0.1	0.1	0.1	0.8	0.2	0.5	0.2
Roll settings									
Frequency	— —	— —	20 Wks.	10 Wks	10 Wks.	10 Wks.	— —	— —	— —
Number	— —	— —	84 Del.	34 Del.	15 Frs.	200 Frs.	— —	— —	— —
Hr./wk.	— —	— —	0.2	0.4	0.2	1.0	— —	— —	— —
Uniformity									
Frequency	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	— —	— —	— —
Number	8 laps	20 cards	14 Frs.	14 Frs.	15 Frs.	20 Frs.	— —	— —	— —
Hr./wk.	3.0	3.0	2.0	2.0	2.0	3.0	— —	— —	— —
Idle Deliveries									
Frequency	— —	— —	Weekly	Weekly	Weekly	Weekly	— —	— —	— —
Number	— —	— —	84 Del.	84 Del.	1500 Spdl.	56.000	— —	— —	— —
Hr./wk.	— —	— —	0.1	0.1	1.0	2.0	— —	— —	— —
Relative Humidity									
Frequency	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	— —	Weekly	Weekly
Number	— —	— —	— —	— —	— —	— —	— —	— —	— —
Hr./wk.	0.1	0.2	0.1	0.1	0.1	0.5	— —	1.0	0.1
Misc. hr./wk.	— —	10.0	1.0	1.0	0.2	1.0	1.0	1.0	10.0
Total, hr./wk.	3.7	14.2	4.5	8.7	9.6	11.3	1.2	2.5	15.3