Studies on the Reduction of Coefficient of Variation: A Case Study

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In a spinning mill, yarn is the final product. Linear density expressed in terms of count is one of the important characteristics of yarn. Because variability of textile strands increases as the linear density increases, the variability in the count is often measured in terms of coefficient of variation (CV)%. The yarn with a high CV% of count leads to a higher end breakage rate during the spinning and subsequent weaving/knitting operations, and consequently, results in lesser productivity and poorer appearance quality of the woven/knitted fabric. When this woven/knitted fabric is dyed, uneven shades are generated. Because the production of yarn involves processing of raw cotton in multimachines at multistages, possible sources that lead to a high CV% of count are many. Enrick's (1960) analysis procedure, which is based on the modification of the range method for analysis of variance, is used conventionally for detecting the stages where excessive "between-machine" differences are present. When the CV% of count is inflated due to the generation of systematic variation in any machine or introduction of high variability by any machine, this inflation remains undetected when using Enrick's procedure. The case study presented here demonstrates that a step-by-step analysis of linear densities of different stage-outputs starting from yarn to card sliver, using appropriate nested design models along with Duncan's multiple range test, is very useful in detecting all possible sources of a high CV% of count of yarn.

Keywords Analysis of variance (ANOVA); Nested design; Coefficient of variation (CV%); Duncan's multiple range test.

INTRODUCTION

In a spinning mill, yarn is the final product. The linear density of a yarn is expressed in terms of count, which is defined as the "number of 840-yard length per pound." The linear density or count of a yarn indicates its fineness, and governs the appearance and behavior of the various types of yarns and fabrics. Higher variability of linear density implies presence of a larger number of thin and thick places along the length of the yarn. Consequently, the yarn with higher variability of count leads to higher end breakage rate during the spinning and subsequent weaving/knitting operations, resulting in lesser productivity and poorer appearance quality of the woven/knitted fabric. When this woven/knitted fabric is dyed uneven shades are generated (Booth, 1968).

It may be noted that a yarn is produced by giving twist to a long thin strand of cotton prepared by gradual cleaning and attenuation (i.e., drafting) of a mass of raw cotton. The production of yarn involves processing of raw cotton in multimachines at multistages. The outputs from a set of machines in a stage (called stage-output) are fed randomly into several machines at the succeeding stage. As the operations are in series, the variation induced at any stage ultimately flows to the final output (i.e., yarn resulting in high variability of count). It is well known that variability of textile strands increases as the linear density increases. Thus, CV% is considered as a good measure of variability of linear density because it permits ready comparison of different yarns and intermediate stage-outputs (e.g., rovings, slivers), without need to refer to the particular weight involved.

One of the important sources of high variability in any stage-output is the presence of between-machine differences. Enrick (1960) formulated the rules of variation flows and proposed an analysis procedure, based on the modification of the range method of analysis of variance (ANOVA), for tracing the within-machines and overall variation at different stages of operations. The stages of operations having excessive between-machine differences are detected by comparing the values of the ratio of overall variation with the within-machine variation with the critical values of the modified F-ratio provided by him.

Because Enrick's procedure is simple and easy to understand, this procedure is conventionally used in

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textile industries for analysis of variation flow and detection of stages requiring corrective actions. However, it is well known that due to the nature of operations, the machinery used for fiber processing are prone to generate systematic (e.g., periodic) variation. This systematic variation flows to the yarn and inflates the CV% of count. The CV% of count is also inflated if there is a high variation in the output of one or some machines in a stage of operation. To ensure CV% of count is maintained at the minimum level, it is essential to eliminate between-machine differences of average levels of linear density at different stages of operations, identify other sources of variation, and take appropriate corrective measures.

The case study presented in this article describes an approach of study for detecting all possible sources that lead to high CV% of count of yarn. It is demonstrated that a step-by-step analysis of linear densities of outputs at different stages—from yarn to card sliver—using appropriate nested design models is very useful for this purpose.

This study is carried out in an Indian traditional spinning mill for the yarn of 20^s count, which is its regular product. The average CV% of this yarn is as high as 4.22%, whereas the industrial standard is 2% to 3% (Garde and Subramaniam, 1989).

THE PROCESS

The different stages of operations for processing of raw cotton and their sequences are given in Figure 1. The yarn of 20^s count is produced in a dedicated set of blowroom (BR), cards, drawframe (DF)-breakers, DF-finishers, simplexes and ringframes (RF). Only one BR line is used for processing of the raw cotton. In BR, the fiber tufts are opened up, most of the trash materials are removed, and then a thick uniform sheet of cotton is produced. Every 39-yard length of the sheet is rolled to a rod. This rolled sheet is called a lap.

The laps are fed into several cards for further processing. In a card, the fiber tufts are further opened up into individual fibers, short fibers and remaining trashes are removed, and then card sliver (continuous long strand of cotton) is formed. The card sliver is stored in cans.

The card slivers are processed in two DF-breakers. Each DF-breaker has two heads (output positions). Eight card slivers are fed simultaneously into a head of a DF-breaker, where they are blended together. At the same time, drafting takes place, which is about eight so output of the DF-breaker (known as DF-breaker sliver) has approximately the same linear density as each of the several card slivers fed. The DF-breaker slivers are stored in cans.

The DF-breaker slivers are processed in two DF-finishers. The operation in the DF-finisher is the same as in the DF-breaker. Eight DF-breaker slivers are fed simultaneously into a head and after blending and drafting these are converted to one sliver (known as DF-finisher sliver). The DF-finisher slivers are stored in cans.

The DF-finisher slivers are further processed in simplexes. During processing in a simplex, a draft of 10 is given to a DF-finisher sliver to form a finer long strand of fibers, called roving. The rovings are wound into bobbins. Each simplex machine has 120 spindles. So, there are 120 feed and output positions in each simplex.

The bobbins of roving are fed into RFs, where a draft of about 20 is given to the roving and simultaneously twist is given to the attenuated strand of fibers so the yarn of 20^s count is formed. The yarn is wound into wooden cops. There are 440 spindles in a RF. So, there are 440 input and output positions in each RF.

Measurements Made at Different Stages of Processing

For the purpose of controlling the average linear density in a particular stage of operation, samples of fixed length are collected from the output of the stage and their weights (in grams) are measured. The practice in the mill is to weigh a 6-yard length of sliver, a 15-yard length of roving, and a 120-yard length of yarn. The mill obtains at least one measurement of weight from the output of each machine at each stage in a shift. The CV% is used as a measure of variability in a stage-output because it permits ready comparison of different yarns, rovings, or slivers, without need to refer to the particular weight involved.

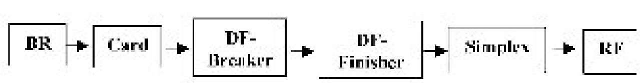

Figure 1. Stages of operations and their sequences in manufacturing of yarn.

THE PROBLEM

It is obvious that CV% of count of yarn is inflated when any of the following situations prevail:

1. There is differences in average levels among machines in any of the stages of operations.
2. Systematic variation is generated in any machine during a stage of operations.
3. There are high variations in the outputs of one or more machines at any of the stages of operations.

Therefore, identification of the machines having different average levels, generating systematic variation, or introducing high variation is important to initiate appropriate corrective measures. However, it is not possible to make these identifications analyzing the available routine data.

OBJECTIVES

The objectives of the study are

1. To identify the source(s) of systematic variation that flows to the yarn
2. To identify at different stages of operation
   a. The machines having different mean settings
   b. The machines introducing high variation.

APPROACH

It is decided to follow the conventional system of measurements for measuring linear densities of outputs of different stages of operation. The presence of a systematic variation in the output of a stage of operation may be the effect of systematic variation present in the previous stage output, or it may be generated in that particular stage. Therefore, the formulation of some guidelines is necessary for identification of the true cause. These guidelines are formulated in a brainstorming session where all the technical personnel of the mill participated, and these guidelines are described as follows.

Because CV% of count of yarn is of ultimate interest, it was believed that data on linear densities of yarn should be collected and analyzed first. Different bobbins are fed to different spindles of an RF, and from a bobbin, a number of cops of yarn are produced in a spindle. The cops produced from the same input bobbin in a spindle of an RF may differ due to the presence of short/medium-term (i.e., within bobbin) systematic variation in roving or due to some mechanical problem in the spindle. However, cops produced in two different spindles of an RF may differ due to the presence of long-term (i.e., between bobbins) variation in roving or due to unequal performances of the spindles. However, a reasonably good assumption can be made regarding the actual cause of the above two kinds of phenomena by analyzing the previous stage outputs (i.e., roving). For example, if linear densities of rovings in different bobbins produced in the simplexes are not equal, it can be safely assumed that the difference between spindle/RF is due to the presence of a long-term variation in roving. Otherwise, it should be considered that the performances of the spindles within an RF are not equal. Thus, breaking up of overall variation in the outputs of RFs in hierarchical structure will reveal the type of variation present in yarn, and similar analysis of the roving will help identify if the type of variation is generated during RF operation or is the result of flow of variation from roving. Similarly, breaking up of overall variation in DF-finisher slivers in a suitable hierarchical structure will reveal if any particular type of variation in rovings is generated during the simplex operation or is the result of flow of variation from the DF-finisher slivers.

Because blending (i.e., averaging) takes place in DF-finisher, no systematic pattern of variation of DF-breaker slivers prevails in the DF-finisher slivers. Therefore, any systematic variation in DF-finisher slivers must be generated during DF-finisher operation. Similarly, because blending of card slivers takes place in DF-breaker, no systematic pattern of variation of card slivers prevails in the DF-breaker slivers and so systematic variation in DF-breaker slivers, if any, is generated during DF-breaker operation. It may be noted that due to blending, the variability in the DF-breaker slivers becomes lesser than that of the card slivers. However, the amount of reduction in variability will be less if systematic variation is present in the card slivers. Therefore, breaking up of overall variation in card slivers in a suitable hierarchical structure should also be made to identify if any systematic variation is present in the card slivers.

It is important to note that the plan of data collection for a stage output should depend on the results of analysis of its succeeding stage output. For example, if there is differences between cops/spindles/RF, the samples of roving should be collected from different positions over the length of roving contained in a bobbin so that differences between positions/bobbin/spindle/simplex can be tested. If differences between cops/spindles/RF are insignificant, but differences between spindles/RF are significant, collection of samples from different bobbins irrespective of position is sufficient. Therefore, it was decided to collect data and analyze it step by step starting from yarn to card slivers. Furthermore, it was planned to complete the entire study during the period of usage of a single batch of raw cotton.

As breaking up of overall variation of the output of each stage of operation in hierarchical structure is of interest here, it is planned to analyze the collected data from each stage using ANOVA techniques for nested design (Montgomery, 1984).

It may be noted that the output of a stage of operation is fed randomly to the machines of its succeeding stage of operation. Therefore, CV% of linear densities should be of the same magnitude in all the machines at a particular stage. CV% is approximately normally distributed with

$$E(CV\%) = \frac{\sigma}{\mu} \times 100$$

$$V(CV\%) = \frac{\sigma^2}{n\mu^2}\left(\frac{1}{2} + \frac{\sigma^2}{\mu^2}\right) \times 100^2$$

The accuracy of this approximation is very good especially for small CV% and moderately large n (Inglewicz and Mayers, 1970). Therefore, it will be appropriate to carry out Duncan's (1955) multiple range test after homogenization of variance of CV% for identification of the machines introducing high variation in a stage of operation.

DATA COLLECTION AND ANALYSIS

Weight of Yarn/120-Yard Length

Four spindles are selected randomly in each RF producing 20^s yarn. Two cops produced from a single input bobbin in each selected spindle are collected. Then, two consecutive samples of 120-yard length are taken from each cop, and their weights are measured. Thus, from the output of each RF, 16 measurements on weight are taken. It may be noted that the count of yarn is estimated from the weight of a 120-yard length of yarn using the following conversion:

$$\text{Count} = \frac{64.8}{\text{Weight of a 120 − Yard length (grams)}}$$

To maintain the convention, the weight data are converted to count and then analyzed. The analysis is carried out using a three-stage nested design for ANOVA. The results of analysis of weight of yarn are given in Table 1.

Table 1
ANOVA of weight of yarn/120-yard length

Source	d.f.	SS	MSS	F-Ratio
RF	5	7.37	1.474	<1
Spindles/RF	18	28.43	1.579	2.65*
Cops/spindles/RF	24	14.30	0.596	1.52
Error	48	18.82	0.392	
Total	95	68.92		

*⇒ Significant at 5% level.

It is noted from Table 1 that there is no significant difference in the average levels among RFs. But the linear densities in the yarns produced in different spindles within RF differ significantly. This implies that either linear densities of roving in different bobbins are unequal or performances of spindles within RF are unequal. To identify the true cause, therefore, linear densities of rovings need to be measured and analyzed.

The estimated overall CV% in the outputs of RFs is 4.22%. RF-wise CV% and $s^2(CV\%)$ (i.e., estimated variance of CV%) are shown in Appendix A. Because the calculated value of $s^2_{\max}(CV\%)/s^2_{\min}(CV\%) = 4.43$ is less than 4.68 (the value of upper 5% points of the distribution of $s^2_{\max}/s^2_{\min}$ for $k = 6$ and $\nu = 15$), it is concluded that RF-wise $s^2(CV\%)$ are homogeneous. The common estimate of variance of CV%, $s^2_p(CV\%)$ is 0.545. From Duncan's tables of significant ranges, the values of $r_{0.05}(p,f)$ for $p = 2, 3, .., 6$, where f is the number of degrees of freedom of error variance, are obtained. These ranges are converted into a set of 5 least significant ranges (R_p) for $p = 2, 3, .., 6$, by calculating

$$R_p = r_{0.05}(p,f) \times s_p(CV\%)$$

The values of least significant ranges at 5% level are $R_2 = 2.22$, $R_3 = 2.33$, $R_4 = 2.40$, $R_5 = 2.44$, and $R_6 = 2.48$. RF-wise CV% are arranged in ascending order, and then differences of different pairs of RF-wise CV% are compared with the relevant R_p values. It is noted that CV% of count is significantly higher in the yarns produced in RF number 15 than CV% of all other RFs. This implies that RF number 15 introduces higher variability than other RFs.

Weight of Roving/15-Yard Length

Different cans of DF-finisher slivers are fed to different spindles of a simplex, and from the length of sliver contained in a can, a number of bobbins are produced in a spindle. Bobbin-to-bobbin difference may occur in the following ways: (1) bobbins produced in different simplexes are different; (2) bobbins produced in different spindles of a simplex are different; and (3) bobbins produced in a spindle of a simplex are different. Keeping this in mind, the data on rovings are collected. Four spindles are selected randomly from each simplex producing roving for 20^s yarn. Two bobbins produced in each selected spindle from a single input can of DF-finisher sliver are collected. Then, two consecutive samples of 15-yard lengths are taken from each bobbin and their weights are measured. Thus, from the output of each simplex, 16 measurements on weight are taken.

The data are analyzed using a three-stage nested design for ANOVA. The results of the analysis are given in Table 2. The ANOVA Table 2 reveals there are significant differences between simplexes, which imply average levels in the simplexes are unequal. It is noted from the simplex-wise averages (see Appendix B) that simplex numbers 4 and 5 produce rovings of lesser linear density than the simplex numbers 9 and 10. The ANOVA table further reveals that there is significant difference between bobbins/spindles/simplex. This is an indication that medium/short-term variation may be present in the DF-finisher sliver. To verify this conjecture, linear densities of DF-finisher slivers are measured and analyzed.

The estimated overall CV% in the outputs of simplexes is 3.41%. Simplex-wise CV% and $s^2(CV\%)$ are shown in Appendix B. Because the calculated value of $s^2_{\max}(CV\%)/s^2_{\min}(CV\%) = 2.82$ is less than 4.01 (the value of upper 5% points of the distribution of $s^2_{\max}/s^2_{\min}$ for k = 4 and $\nu = 15$) it is concluded that simplex-wise $s^2(CV\%)$ are homogeneous. The common estimate of variance of CV% is 0.301. Duncan's multiple-range test reveals that differences between all the pairs of simplex-wise CV% are statistically insignificant. This implies that variations introduced in different simplexes are of the same order.

Table 2
ANOVA of weight of roving/15-yard length

Source	d.f.	SS	MSS	F-Ratio
Simplex	3	1.10	0.367	10.48*
Spindles/simplex	12	0.42	0.035	<1
Bobbins/spindles/simplex	16	1.22	0.076	2.05*
Error	32	1.20	0.037	
Total	63	3.94		

Weight of DF-Finisher Sliver/6-Yard Length

The DF-finisher slivers between cans may differ due to difference in settings among DF-finishers or difference of performances between heads within a DF-finisher. The linear densities at different portions along the length of DF-finisher sliver contained in a can may differ due to generation of periodic waves while drafting takes place. Keeping this in mind, data on DF-finisher sliver are collected. One can of DF-finisher sliver is collected from each head of each DF-finisher. The total length of DF-finisher sliver contained in a can is divided into eight divisions. Two consecutive samples of 6-yard length are taken from each division and their weights are measured. Thus, in total, 32 measurements on weight are taken from the output of each DF-finisher.

The weights of DF-finisher slivers are analyzed using a four-stage nested design for ANOVA. The results of the analysis are given in Table 3. Because only one can of sliver is collected from each head, between heads/DF-finisher effect is denoted here as between cans/DF-finisher. The ANOVA Table 3 reveals that there are significant differences between 2 Div./2 Div./2 Div./Cans/DF-finisher. The technical personnel of the mill explain that this can happen if periodic waves are generated in any DF-finisher while drafting takes place.

The estimated overall CV% in the outputs of DF-finishers is 2.71%. DF-finisher-wise CV% and $s^2(CV\%)$ are shown in Appendix C. Because the calculated value of $s^2_{\max}(CV\%)/s^2_{\min}(CV\%) = 1.85$ is less than 2.02 (the value of upper 5% points of the distribution of $s^2_{\max}/s^2_{\min}$ for $k = 2$ and $\nu = 31$) it is concluded that DF-finisher-wise $s^2(CV\%)$ are homogeneous. The common estimate of variance of CV% is 0.107.

Table 3
ANOVA of weight of DF-finisher sliver/6-yard length

Source	d.f.	SS	MSS	F-Ratio
DF-F	1	0.77	0.77	<1
Cans/DF-F	2	5.55	2.775	1.54
2 Div./Cans/DF-F	4	5.79	1.448	2.09
2 Div./2 Div./Cans/DF-F	8	5.54	0.693	1.42
2 Div./2 Div./2 Div./Cans/DF-F	16	6.87	0.429	2.26*
Error	32	6.08	0.190	
Total	63	30.60		

Equality of DF-finisher-wise CV% is tested using Z-test. The calculated $|Z|$ value is 8.56. Because $|Z_{0.025}| = 1.96$, it is concluded that CV% of linear densities in the outputs of the two DF-finishers are different. The CV% of linear densities in the output of DF-finisher number 5 is higher. This high value of CV% indicates that difference between 2 Div./2 Div./2 Div./Cans exists in the output of DF-finisher number 5.

Weight of DF-Breaker Sliver/6-Yard Length

One can of DF-breaker sliver is collected from each head of each DF-breaker. The total length of the DF-breaker sliver contained in a can is divided into eight divisions. Two consecutive samples of 6-yard length are taken from each division and their weights are measured. Thus, in total, 32 measurements on weight are taken from the output of each DF-breaker.

The weights of DF-breaker slivers are analyzed using a four-stage nested design for ANOVA. The results of the analysis are given in Table 4. Because only one can of sliver is collected from each head, between heads/DF-breaker effect is denoted here as between cans/DF-breaker. The ANOVA Table 4 reveals that all the sources considered are insignificant statistically.

The estimated overall CV% in the outputs of DF-breakers is 2.97%, which is quite high. DF-breaker-wise CV% and $s^2(CV\%)$ are shown in Appendix D. Because the calculated value of $s^2_{\max}(CV\%)/s^2_{\min}(CV\%) = 1.11$ is less than 2.02 (the value of upper 5% points of the distribution of $s^2_{\max}/s^2_{\min}$ for $k = 2$ and $\nu = 31$), it is concluded that DF-breaker-wise $s^2(CV\%)$ are homogeneous. The common estimate of variance of CV% is 0.139. Equality of DF-finisher-wise CV% is tested using Z-test. The calculated $|Z|$ value is 1.50. Because $|Z_{0.025}| = 1.96$, it is concluded that CV% of linear densities in the outputs of the two DF-breakers are not different.

Table 4
ANOVA of weight of DF-breaker sliver/6-yard length

Source	d.f.	SS	MSS	F-Ratio
DF-B	1	2.31	2.31	<1
Cans/DF-B	2	8.83	4.42	2.25
2 Div./Cans/DF-B	4	7.84	1.96	2.61
2 Div./2 Div./Cans/DF-B	8	6.03	0.75	1.74
2 Div./2 Div./2 Div./ Cans/DF-B	16	6.90	0.43	1.79
Error	32	7.71	0.24	
Total	63	39.62		

Weight of Card Sliver/6-Yard Length

There are a large number of cards, which produce slivers for 20[s] mixing. For the study purpose, only 10 cards are selected. In a card, a number of cans of slivers are produced from a single lap. Three cans of card slivers produced in a card from the same input lap are collected, and then four consecutive samples of 6-yard length are taken from each can and their weights are measured. Thus, in total, 12 measurements on weight are taken from the output of each card.

The collected data are analyzed using a two-stage nested design for ANOVA. The results of the analysis are given in Table 5. It is noted from Table 5 that no individual sources considered is statistically significant.

The estimated overall CV% in the outputs of cards is 6.17%. Card-wise CV% and $s^2(CV\%)$ are shown in Appendix E. Because the calculated value of $s^2_{\max}(CV\%)/s^2_{\min}(CV\%) = 3.11$ is less than 7.83 (the value of upper 5% points of the distribution of $s^2_{\max}/s^2_{\min}$ for $k = 10$ and $\nu = 11$), it is concluded that card wise $s^2(CV\%)$ are homogeneous. The common estimate of variance of CV% is 1.44. Duncan's multiple-range test reveals there is no differences between cards with respect to CV%. This implies that variations introduced in different cards are of the same order.

It may be noted that although the effect of the individual sources studied is statistically significant, the overall CV% in the outputs of cards is quite high (6.17%). From a discussion with the technical personnel of the mill, it is learned that this may happen due to the presence of short-term variation in the laps. If there is a short-term systematic variation within the length of the laps, it should be reflected within the length of card sliver contained in a can. Therefore, further data are collected on the weight of card sliver according to the following plan: a single can of card sliver is selected, and the total length of sliver contained in the can is divided into sixteen divisions. Then, two consecutive samples of 6-yard length are taken from each division and their weights are measured. The collected data are analyzed using four-stage nested design for ANOVA. The results of the analysis are given in Table 6.

Table 5
ANOVA of weight of card sliver/6-yard length

Source	d.f.	SS	MSS	F-Ratio
Cards	9	60.72	6.75	1.99
Cans/card	20	67.70	3.39	1.58
Error	90	193.41	2.15	
Total	119	321.83		

Table 6
ANOVA of weight of 6-yard lengths of card sliver

Source	d.f.	SS	MSS	F- Ratio
2 Div	1	2.44	2.44	<1
2 Div./2 Div.	2	10.60	5.30	<1
2 Div./2 Div./2 Div.	4	26.64	6.74	3.94*
2 Div/2 Div./2 Div./2 Div.	8	13.69	1.71	1.17
Error	16	23.28	1.46	
Total	31	75.95		

It is observed from Table 6 that there is a significant difference between 2 Div./2 Div./2 Div. within the length of a sliver of a can. Technically, generation of this kind of variation due to carding operation is very unlikely, and therefore, it is concluded that there is short-term variation within the lap. Taking into account the length of sliver that is contained in a can and the amount of draft given to the lap, the length that varies within lap is estimated to be about 0.44 yards.

CONCLUSION

The sources that contribute to the high CV% of count of yarn are the following:

1. Generations of short-term variation in the form of differences between 2 Div./2 Div./2 Div./Can in the output of DF-finisher number 5.
2. Generation of short-term variation in the form of differences between 0.44 yard lengths within lap.
3. Production of rovings of lesser linear density in the simplex numbers 4 and 5.
4. High variability introduced by the ringframe number 15 during spinning operation.

FOLLOW-UP ACTIONS

The findings of the study were presented to the technical personnel of the mill for identification of necessary corrective actions from a technical point of view. Because the sources that contribute to the high CV% of count of yarn became known, the corrective measures that should be taken could be identified easily. Accordingly, a number of corrective actions were taken, and these are described here:

1. In simplex numbers 4 and 5, the draft was adjusted so the linear densities of rovings produced in the four simplexes match closely.
2. The management stopped running of RF number 15 for production purposes and handed it over to the maintenance department for overhauling. Greasing, oiling, etc. were carried out thoroughly, worn out/loose parts were replaced, and all parts were reset carefully.
3. Improper opening of fiber tufts and malfunctioning of the leveler is known to be the causes of presence of short-term variation in the lap. In BR, therefore, the setting of feed roller to spike of porcupine opener was reduced. All other settings and speed of rollers/beaters were checked and adjusted. Further more, the piano feed mechanism (which acts as a leveler) was overhauled thoroughly.
4. In DF-finisher number 5, the drafting rollers were checked for eccentricity and adjusted. Worn-out/loose parts were replaced.

Table 7
Estimated mean and CV% of count (before and after follow-up actions)

Characteristics	Before follow-up action	After follow-up action
Mean	20.19	20.08
CV%	4.60	2.02

RESULTS

Subsequent to the follow-up actions taken, data are collected again in RF section to assess the impact of those actions. Four spindles are selected randomly in each RF. Two cops produced in each selected spindle from a single input bobbin are collected. Then, two consecutive samples of 120-yard lengths are taken from each cop and their weights are measured. Thus, there is a total of 96 measurements on weight. The estimated overall average and CV% before and after the follow-up actions taken is given in Table 7.

CONCLUDING REMARKS

Because Enrick's procedure is simple, easy to understand, and applicable on the routine data collected for control purposes, this procedure is conventionally used in textile industries for analysis of variation flow and detection of stages requiring corrective actions. By doing this, other important sources like generation of systematic variation in any machine or introduction of high variability by any machine that contribute to a high CV% of count remain undetected.

A step-by-step data collection and analysis of linear densities of different stage-outputs starting from yarn to card sliver using appropriate nested design models is very useful in detecting the other sources. The CV% of count resulted after taking all necessary corrective measures may be considered as the minimum level achievable in a mill. After ensuring that CV% of count is at the minimum level, Enrick's analysis procedure should be used routinely for quick detection of between-machine differences that may arise in a stage of operation. Also, from time to time, a detailed study as described in this article should be carried out to ensure that CV% of count is not inflated due to other sources.

ABOUT THE AUTHOR

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Appendix A

RF-wise average and CV% of weight of 120-yard lengths of yarn

RF No.	No. observations	Mean	CV%	$s^2(CV\%)$
13	16	19.74	3.05	0.291
14	16	20.27	3.77	0.445
15	16	20.49	6.39	1.288
32	16	20.35	3.14	0.309
34	16	19.88	3.46	0.375
35	16	20.39	4.23	0.561
Overall	96	20.19	4.22	0.545

Appendix B

Simplex-wise average and CV% of weight of 15-yard lengths of roving

Simplex No.	No. observations	Mean	CV%	$s^2(CV\%)$
4	16	7.153	3.91	0.479
5	16	7.273	2.33	0.170
9	16	7.483	3.20	0.321
10	16	7.437	2.74	0.235
Overall	64	7.337	3.41	0.301

Appendix C

DF-finisher-wise average and CV% of weight of 6-yard lengths of sliver

DF no.	No. observations	Mean	CV%	$s^2(CV\%)$
ING-3	32	26.74	2.19	0.0751
LR-5	32	26.52	2.89	0.1389
Overall	64	26.63	2.71	0.107

Appendix D

DF-breaker-wise average and CV% of weight of 6-yard lengths of sliver

DF no.	No. observations	Mean	CV%	$s^2(CV\%)$
ING-1	32	26.86	3.05	0.145
ING-2	32	26.48	2.91	0.132
Overall	64	26.67	2.97	0.139

Appendix E

Card-wise average and CV% of weight of 6-yard lengths of sliver

Card No.	No. Observations	Mean	CV%	$s^2(CV\%)$
1	12	26.61	4.88	1.00
2	12	26.08	7.61	2.43
3	12	27.21	5.32	1.19
4	12	26.99	4.34	0.78
10	12	25.91	6.10	1.56
11	12	25.23	6.85	1.98
13	12	26.03	4.68	0.92
14	12	26.58	5.76	1.38
15	12	27.32	4.49	0.85
16	12	26.58	7.42	2.32
Overall	120	26.58	6.17	1.44