# SETTING PRACTICAL SCIENTIFIC CRITERIA FOR COTTON FIBER SELECTION AND BLENDING

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## Introduction

In recent years, revolutionary developments have been made in the area of fiber and yarn information systems. In conjunction with these developments, powerful techniques of fiber selection and blending have been introduced. These techniques aim at optimizing the utilization of cotton fiber properties with respect to a particular spinning system and/or an end product. The technical objective of a fiber selection technique is to select uniform cotton mixes or bale-laydowns from a bale population [1,2]. The economical merits of fiber selection are reflected in better bale management and optimum cost of fiber blend components [3,4].

The basic assumption of a fiber selection process is that a uniform fiber profile fed to the fiber-to-yarn conversion system should yield a uniform yarn profile under strictly controlled processing conditions. It is generally true that a non-uniform fiber profile will always produce a non-uniform yarn profile no matter how modern the machine used or how optimum the process settings. However, any claim that a uniform fiber blend will always produce a uniform product will clearly lack the accuracy and the evidence to support it. The real dilemma with making such a claim lies in the absence of a true relationship between fiber blend uniformity and yarn or fabric uniformity. Some of the reasons for the absence of such relationship are as follows:

1. Standard parameters used to characterize both fiber and yarn uniformities are of a single-sided nature in the sense that they tend to describe irregularity rather than uniformity. That is why the fact that a non-uniform fiber profile will produce a non-uniform fiber profile has no reliable inverse.

2. The limiting irregularity, or the irregularity resulting from a pure random arrangement of fibers in the fiber strand at no process-added variability [6-9] is ill-defined and only represents a limited view of fiber blending.

3. There is a significant gap between the standard parameters used to characterize the uniformity of fiber blending and those used to describe yarn or sliver uniformity. This gap is attributed to the use of different sample space, different geometry, and different testing techniques. Accordingly, even if a true relationship does exist between fiber blend uniformity and yarn uniformity, it is difficult to pinpoint such a relationship due to the lack of correspondence in the characterization parameters.

   We should point out that the lack of correspondence does not mean that these parameters are not useful; it simply limits their usefulness in connection with the development of a product with a pre-specified uniformity level.

In the absence of well-established relationships between parameters characterizing fiber blend uniformity and those characterizing yarn uniformity, any effort to improve end product uniformity will largely be a work of art. More seriously, costly problems associated with irregularity in the process or with end product irregularity will continue to occur and no objective solutions can be provided.

The majority of quality problems witnessed in the textile process can be attributed in one way or another to some form of variability in the input fiber profile. Even in situations where the machine seems to play an obvious role, there may be a possibility that the machine which is normally set according to average values of fiber parameters is failing to accommodate the high variability in the entering fibers.

Traditionally, textile technologists tend to think of variability-related problems as those that are mainly associated with extreme yarn irregularity, high variation in dye uptake, color streaks, or fabric barre. This traditional thinking is largely attributed to the direct and measurable impact of these problems on the cost of manufacturing and customer's satisfaction. Objectively, irregularity-related problems should be divided into three categories [see Figure 1]. Typical examples of each category are given in Table 1. The significance of this categorization lies in the fact that irregularity-related problems always occur; yet our attention is often timed with the excessiveness of occurrence rather than the frequency of occurrence. If one examine the frequency of occurrence of a quality problem over a long period of time, one will obtain a better estimate of the cost associated with the problem.

In addition, irregularity-related problems are often masked by the way parameters are reported. For example, we often report machine efficiency by the overall avrage of efficiency (the C.G. of the frequency distribution) and overlook units that yield exceptionally high or low efficiencies. Commonly, the frequency distribution of efficiency or endsdown is a skewed one [see Figure 2]. This obviously

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makes the average efficency or endsdown a misleading parameter.

In the following section, some significant theoretical treatments to develop relationships between uniformity parameters of the fiber blend and the uniformity of yarn will be briefly reviewed. Evaluation of these treatments from a practical viewpoint will also be discussed.

## Theoretical Treatments of Fiber Blending

Theoretical analyses of fiber blending are well documented in the literature [e.g. 5-13]. Many of these treatments yielded results that are used in today's commercial testing equipments for the analysis of fiber strand irregularity. These include the familiar Martindale equation [9] which is used as the standard parameter of limiting irregularity.

The common axiom used by most theoretical treatments is that the best that processing machinery can do in the preparation of spun yarns is to arrange the fiber ends in a random order. On the basis of this axiom, a great deal of work was devoted to develop formula for determining the variation in the number of fibers in the cross-section of the fiber strand, and to develop indices of the extent to which a blend deviates from randomness. Some analysis assumed an upper limit to possible number of fibers in a cross-section which is not statistical but determined by the mechanical features of the process delivering the yarn. A lower limit of the number of fibers in a cross-section was also assumed which is determined by the consolidation mechanism used in preparatory or spinning machinery. These assumptions resulted in more general formula which can be reduced to Martindale's equation as a special case.

The practical merits of the theoretical analysis of fiber blend can be realized through examination of the information revealed by the formula developed. From Coplan & Klein [5], the standard deviation of the number of fibers is given by the following equation:

$$\sigma_n = \sqrt{\bar{n}\,\left(1 - \frac{\bar{n}}{n_{\max}}\right)} = \sqrt{\bar{n}\; q}$$

where $\bar{n}$ is the average number of fibers per cross-section, $n_{max}$ is the maximum possible number of fibers per a randomly-selected cross-section, and $q = 1-p$, where $p = \bar{n}/n_{max}$.

The above equation is the typical binomial expression of standard deviation. As p approaches 0 and the upper limit of the number of fibers per cross-section (or $n_{max}$) approaches infinity, the binomial distribution approaches a poisson distribution which provides the basis for the familiar Martindale equation:

$$\sigma_n = \sqrt{\bar{n}}$$

$$C.V_n = 100 \; \frac{standard \;\; deviation}{mean} = 100 \; \frac{\sigma_n}{\bar{n}}$$

$$or \quad C.V_n = \frac{100}{\sqrt{\bar{n}}}$$

Variation in the number of fibers per cross-section resulting from periodic effects (mostly, machine-related) was also considered using the principles of the familiar analysis of variance:

$$\sigma_n = \sqrt{\bar{n}\; q \; + \; n_{\max} \;\; (n_{\max} \; -1) \;\; \sigma^2{}_p}$$

where $s_p$ is a variance characteristic of the periodic influence.

The above equation reveals that variability in the number of fibers per strand cross-section is a function of two main variability components:

(i) the inherent component which results from random variation in fiber dimensions reflected in random allocation of fibers in the strand, and

(ii) the periodic component which results from either mechanical defects or periodic patterns in the fiber mix.

Theoreticians also realized that during processing, fibers do not flow in single-fiber form but rather in a clustered or fiber-group form. This clustering effect may be enhanced by the presence of some fibers exhibiting more or less favorable characteristics than the overall fiber population. Coplan and Klein considered this clustering effect as follows:

$$\sigma_n = \sqrt{C \;\bar{n}\; q}$$

where C is the average number of fiber ends per cluster.

The above equation reveals that the increase in the number of fibers per cluster will increase the variability in the fiber arrangement in the yarn cross-section. The equation also accounts for the average number of clusters in a randomly picked cross-section as defined by $\bar{n}/C$.

The effect of clustering is often realized in extreme situations when clusters of sticky cotton result in clogging a carding machine, or when clusters of short fibers result in excessive end breakage during spinning. In some situations, long/weak fibers are converted into fiber fragments under the effect of mechanical stresses during opening and cleaning. These fragments present themselves in the form of weak slivers and processing problems during drafting.

The classical theoretical treatments discussed above suggest that the variability in the number of fibers per yarn cross-section is largely determined by the extent of randomness in fiber distribution. Thus, the basic connection between fiber blend variability components and yarn variability components is randomness; and any departure from a random fiber distribution will weaken the relationship between these two components. Ideally, a random distribution of a fiber quality in the blend should yield a random distribution of fibers along the yarn length. In addition, the two distributions should exhibit similar forms [see Figure 3].

Obviously, randomization of fiber distribution in the fiber strand is a crucial factor in producing good blend. This randomization justifies the use of the current testing techniques of yarn uniformity. In modern testing techniques, yarn uniformity is defined by the extent of variation in the yarn mass per unit length. Accordingly, the cut and weight or the capacitive method are used in determining thickness variability. When optical methods are used, variation in thickness can be determined for much smaller lengths of yarn.

Theoretically, thickness uniformity is achieved under two main conditions:

(1) Consistent number of fibers per yarn cross-section along the yarn length.
(2) Consistent random distribution of fibers per yarn cross-section along the yarn length

If these two conditions can be achieved, an ideally blended yarn will be produced. A yarn meeting these conditions should exhibit high thickness uniformity, high twist uniformity, and high strength uniformity. Note that the twist uniformity is largely controlled by the variation in yarn thickness (twist migrates heavily to thin places), and the strength uniformity by the variation in the number of fibers per yarn cross-section.

Based on the above discussion, the first criteria of a good blend should be: **"Randomization of fiber distribution in the yarn cross-section"**. In practice, this randomization is achieved through two main procedures:

(i) Selection of cotton fiber mixes from the warehouse population in a random fashion or more precisely in a stratified random fashion (i.e. random selection from pre-set categories).
(ii) Randomization of fiber allocation during processing (pre-blending, mixing, etc.).

## Deviation from Randomization

### Gross Reasons

In view of the above discussion, any relationship between fiber uniformity and yarn uniformity should be evaluated in view of randomization. A failure to detect a direct relationship between these two components should be considered as a result of a significant departure from randomness. The logical question at this point is **"what are the causes of departure from perfect randomization?"**.

Gross reasons for the departure of randomization include:

(1) Non-random (or biased) fiber selection
(2) Improper machine settings

A non-random (or biased) fiber selection can occur even with the use of a seemingly proper selection procedure. For example, any selection procedure assumes that the within-bale variability is insignificant in comparison with between-bale variability. This assumption provides practicality to the process of fiber selection since within-bale variability is not measured on routine basis. In some exceptional situations, however, within-bale variability can become a serious issue. For example, when few bales exhibiting special attributes are inserted into the mix to satisfy economical requirements (e.g. processing waste or re-ginned cottons with primary cottons), within-bale variability may rapidly approach between-bale variability.

In recent years the trend in the U.S.A. has been to replace the individual bale measures by the so-called "module average" which substantially reduces the number of tests through testing a module of about 14 bales and using module average values as measures of individual bales. Although the module average will represent an average of at least 14 observations, no variability measures associated with these observations will be provided (i.e. range or standard deviation). It is our opinion that the introduction of the module average as economical as it may sound will be at the expense of the reliability of using fiber data in any selection strategy. One solution to this problem is to make available the measures of dispersion or variability associated with the module, and to rearrange the marketing scheme so that cotton bales are shipped to the textile mill in module format.

Improper machine settings can cause a significant departure from randomization of fiber components in the blend. In fact, a uniformly selected fiber mix can turn into a disastrous blend if the machine fails to randomly distribute the fiber components of the mix, or if the machine introduces bias to the fiber flow (e.g. breaking fibers). Fortunately, in today's technology the machine maker has reached the highest degree of excellence in machine design at speeds that were not even conceived few years ago. More impressively, fiber attributes are now incorporated in the intelligence systems of modern machinery. Examples of these developments can be seen in the Rieter VarioSet system where fiber length and cleaning propensity are used as basic setting parameters and in the Trutzschler Cleanomat System where different machine components are used to accommodate different types of cotton. Today's automatic bale openers and multi-mixers are quite capable of producing a homogenous mix of cotton fibers, particulary under normal conditions (i.e. optimum throughput rate and optimum laydown size).

**<u>Other Reasons</u>**

**[1] Failure of Breakdown of Fiber Groups**

Most types of blending failures which do not involve long-term periodic variations in the composition of the yarn can be attributed to failures to obtain a breakdown of fiber groups that exhibit similar characteristics (favorable or unfavorable) into single fibers. Our previous work in fiber blending suggests that even if this breakdown can largely be achieved in the early stage of spinning preparation (preparatory fiber opening and blending), the carding or drafting process may cause some fibers of similar characteristics (e.g. long/fine fibers or immature fibers) to regroup. It is also known that when a weaker fiber is blended with a stronger fiber, earlier stages of processing may break more of the weaker fibers with the result being short fibers of one type moving irregularly in the drafting fields.

The above point calls for better understanding of the role of fine openers, particularly carding, in fiber segregation; a phenomenon that is often reflected in high within and between-card variations, particularly in fiber characteristics such as short fiber content, and color.

It is also important to understand the difference between the effect of carding and that of drafting on fiber blending. An early investigation by Lund [6] revealed some interesting findings in this regard. These findings were based on blending two fiber components of different colors (black and white) at two stages of processing; one before carding (commonly known as intimate blending), and one at the drawframe. Comparison was then made between the two yarns produced by these two processes. This comparison was performed by untwisting each yarn, at many points along the yarn length, spreading the fibers out on a microscope slide, and counting the numbers of black and white fibers intersecting a graticule in the eyepiece of the microscope as the field of view is traversed across the width of the yarn. The author found that the frequency distribution of fibers of the same color was almost the same for both intimately-blended yarn and draw-blended yarn [see Figure 4]. This means that both blending techniques have succeeded in achieving sufficient randomization along the yarn length.

Despite the similarity of the fiber distribution of the two yarns, they were significantly different in their extent of irregularity, and the two fabrics produced from the two yarns exhibited completely different color shades (in both cases, the intimate blending produced more satisfactory results). These differences were due to a clustering effect in which each color tends to form aggregates in the yarn cross-section. This effect was more pronounced in the draw-blended yarn than the intimate-blended yarn. This point adds a new dimension to the meaning of randomization discussed earlier. A randomization effect should be achieved in the yarn bulk, i.e. three-dimensional or cylindrical randomization. If this type of randomization could be achieved, a total breakdown of color could be achieved and the cross-sectional color could have been a smooth mix of the two colors.

In practice, a breakdown of fiber aggregates can be accomplished using modern automatic bale openers and a minimum size of fiber tufts being plucked from each bale. Hindering factors in this regard are the size of the bale-laydown (the number of bales), the machine capacity, and the rate of throughput. A multi-dimensional blend [e.g. the Trutzschler inclined system] may yield better breakdown of fiber aggregates, particularly in situations where within-bale variability is of concern.

In view of the above discussion, a second important criteria of fiber blending is **"the size of aggregates of fibers of one component or one bale"** or **"the degree of breakdown into single fiber elements"**.

**[2] The Interactive Nature of Fiber Characteristics**

A departure from randomization may also be caused by a more complex mechanism in which the fiber elements are not represented by their dimensional or frequency characteristics, but rather by their physical attributes. That is fiber blending may be considered as a mix of attributes rather than fibers. The most obvious case in this regard is the blending of two levels of fiber length, very long and very short. In this case, the high level is actually controlled by the machine while the low level is more influenced by uncontrollable surrounding conditions. The resultant effect may be a removal of short fibers as waste or inactive fibers in the yarn. It is for this reason that fiber selection and blending solely on the basis of fiber length can produces a disastrous yarn.

Another example, is the blending of two different categories of fiber strength. Theoretically, these two levels should blend in a linearly-additive fashion provided that they have the same levels of extensibility. If the two levels of strength are also associated with substantially different levels of extensibility, the theory suggests that the resultant strength will be biased toward the fiber of lower extensibility [see Figure 5]. This creates an attributive bias that no machine can correct.

We should point out that the interactive nature of fibers during processing or in the yarn cross-section is largely influenced by their inter-fiber cohesion (fiber friction), and resiliency. These two factors should be introduced in developing any relationship between fiber uniformity and yarn uniformity. In a previous study, we proved that two mixes of identical standard fiber properties can produce completely different levels of yarn irregularity simply because one of the mixes involved cottons of significantly higher friction (dewaxed or heavy rained-on cottons). This issue is even more serious when cotton is blended with synthetic fibers of incompatible surface finish. A survey of the new Uster Statistics (1997) will immediately reveal to the reader that the world quality of cotton/polyester blended yarns are far inferior to those of 100% cotton or 100% polyester. We believe that a great part of the reason for this poor quality is the lack of understanding of the surface compatibility between the two fibers. In this regard, the principle author conducted extensive research that will soon be published in TRJ.

**[3] Induced Defects**

Induced defects commonly consist of trash matter, neps, and short fiber content. A large portion of these defects is normally removed in processing cotton. However, residual defects (fine trash, seedcoat fragments, fiber fragments, dust, etc.) intermingle with fibers in a very complex manner. Different theories have been proposed for the nature of this intermingling. In connection with fiber selection and blending, excessive values of these induced particles can result in a poor blend and poor yarn quality. [see Figures 6 through 16]. These figures describe two mixes that were almost identical in their HVI fiber properties, yet exhibited significant differences in yarn quality due to excessive fiber defects in one of the mixes.

The effects of induced defects call for a fiber selection and blending strategy to control their adverse impact. This is the subject of a current study by the present author. One of the challenges associated with these induced defects is the way they blend together during processing.

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## Literature

1. El Mogahzy, Y., and Y. Gowayed. Theory and practice of cotton fiber selection. Part I: Fiber selection techniques and algorithms. Textile Res. J.,65:32-40, 1995.

2. El Mogahzy, Y. E., and Y. Gowayed . Theory and practice of cotton fiber selection. Part II: Sources of cotton mix variability and critical factors affecting it. Textile Res. J. 65: 75-84, 1995.

3. El Mogahzy, Y. E. Optimizing cotton blend cost with respect to quality using HVI fiber properties and linear programming. Part I: Fundamentals and advanced techniques of linear programming.Textile Res. J. 62:1-8, 1992.

4. El Mogahzy, Y. E. Optimizing cotton blend costs with respect to quality using HVI fiber properties and linear programming. part II: Combined effects of fiber properties and variability constraints. Textile Res. J. 62:108-114,1992.

5. Coplan, M. J., and Klein, W. G., A Study of Blended Woolen Structures, Part I: Statistics of the Ideal Random Blended Yarns, Textile Res. J. 25 (9), 743-754 (1955).

6. Lund, G. V., Fiber Blending, Textile Res. J. 24, 759-764, (1954).

7. Picard, H. C., “The Irregularity of Slivers III”, The Journal of the Textile Institute, vol. 44, No. 7, T307-T316, 1953.

8. Vanden, A., “Contribution to the Study of Irregularity of Yarns, Rovings, and Slivers, J. Textile Inst., 42, P162-172, 1951.

9. Martindale, J. G., A New Method of Measuring the Irregularity of Yarns with some Observations on the Origin of Irregularities in Worsted Slivers and Yarns, J. Textile Inst. T35 (1945).

10. Walker, P. G., Statistical Tests of Color Blending in Roving, J. Textile Inst. 48, T133 (1957).

11. Zurek, W., "The Structure of Yarn", (translated from Polish), Foreign Scientific Publications Department, National Center for Scientific, Technical and Economic Information, Warsaw, Poland, 1975.

12. Zurek, W., and Krucinska, I., A Probablistic Model of Fiber Distribution in Yarn Surface as a Criterion of Quality, Textile Res. J., 49, 438 (1979).

13. Zurek, W., and Sobieraj, I. and Trzesowska, T., Properties of Blend Yarns, Textile Res. J. 49, 438 (1979).