DEVELOPING WAYS TO DETERMINE THE BLENDING PERFORMANCE OF MULTI-COMPONENT FIBER MIXTURES PART I: THE ANALYTICAL APPROACH Yehia El Mogahzy Department of Textile Engineering Auburn University Auburn, AL

<u>Abstract</u>

This paper represents a small part of an extensive study sponsored by Cotton Incorporated and the National Textile Center. In this study, we developed a new integrated analytical and experimental approach for handling the different aspects of fiber blending. In this Part of the study, we discuss the analytical approach. This is based on classifying the blending phenomenon into four basic modes: structural blending, attributive blending, appearance blending, and interactive blending. Structural blending implies the extent of geometrical allocation of different fiber segments within the structural boundaries of the fiber strand. Attributive blending describes the extent of nonogenization of color or component apparent intensity in the fiber assembly. Interactive blending implies the interaction between different fiber components during the blending process. The concepts underlying the analyses of these different blending modes are discussed.

Introduction

Fiber blending is commonly defined as the process of forming a fiber mixture by combining different fiber components, either of the same fiber type or of different fiber types, together to produce a homogenous fiber assembly. When components of the same fiber type (e.g. cotton lots or cotton bales of different characteristics) are blended together, the main purpose of blending is typically to produce consistent fiber mixture in which fibers from these components are equally represented in the cross section and along the length of the fiber assembly. When components of different fiber types (e.g. cotton and polyester) are blended, the main purpose is typically to produce a fiber assembly of homogenous fiber mixture that exhibits predetermined values of fiber characteristics that cannot be found in only one type of fibers.

Over the years, the process of fiber blending has received a great deal of attention particularly in the practical environment. The need to produce a homogenous fiber mixture from hundreds of fiber lots processed together through the opening line has resulted in the development of many innovative fiber handling equipments such as high capacity automatic bale openers and multi-mixing units [10, 18]. The introduction of capable and efficient fiber testing and information systems has resulted in improving the knowledge of the fiber characteristics critical for efficient fiber blending [5, 16]. In addition, the increasing demand for natural/synthetic fiber blends has greatly improved the weighting and blending techniques of different fiber types during processing [10].

The subject of fiber blending also had its extensive share of research with the common focus being on the irregularity of blended fiber strands. In 1940's, Martindale [22] introduced his familiar simple equation of yarn irregularity. Following this study, many investigators analyzed the irregularity of fiber assemblies using rigorous mathematical analyses [2, 3, 21, 24-26, 29, 31-35]. These efforts resulted in providing a great deal of insight into the phenomenon of blended yarn irregularity and in developing testing techniques for measuring the irregularity of fiber strands [5, 30].

In early 1980s, Cotton Incorporated of the U.S.A. developed the Engineered-Fiber-Selection EFS° system in conjunction with the High Volume Instrument (HVI^{\circ}). This system aims at providing textile mills with computer-based fiber selection and blending techniques [5, 16]. This development has revived the interest in the subject of fiber blending. In support of EFS° system, new methods of fiber selection and blending were developed using different simulation analyses [8, 9, 15, 19, 28]. The common objective of these methods was to minimize within-mix irregularity. In addition, some investigations focused on the economical aspects of fiber blending [13, 14].

Despite the extensive research on the subject of fiber blending, many questions related to this critical phenomenon remained unanswered. These questions are primarily driven by technological and quality problems that are often experienced even with fiber blends that are pre-selected to achieve minimum within-mix variability. Indeed, situations frequently occur where blending of fibers of seemingly compatible attributes fail to produce the intended values of fiber or yarn characteristics with respect to the blend ratio used. Quality and technological problems caused by this failure are often detected at a very late stage of processing, typically in the dyed and finished fabric form. These problems include fabric defects, color shade variation, fabric barré, fabric skewness, and dimensional instability. Furthermore, blending has been perceived as a proactive approach in which efforts are made to feed a consistent fiber mixture to the textile operation, yet no output parameters charac-

terizing the blending performance are available. These practical concerns represent the key objectives of the present study. Specifically, this study aims at achieving two main objectives:

- 1. Establishing an integrated approach of fiber-blending analysis
- 2. Developing reliable experimental techniques for evaluating the nature of fiber blending

In this part of the study, we discuss the analytical aspects of the integrated approach to characterizing fiber blending.

The Integrated Approach to Fiber Blending Analysis

As indicated earlier, fiber blending has been the focus of many previous investigations. The common objective of these investigations has been the evaluation of the structural integrity of yarns produced from blending of fibers of the same type or of different types. Accordingly, blending analysis primarily focused on the variability in the number of fibers per yarn cross-section or along the length of a yarn segment. Our analytical approach aims at a more integrated evaluation of fiber blending. In this regard, we classify the outcome of fiber blending into four basic modes:

- 1. Structural blending-This implies the extent of geometrical allocation of different fiber segments within the structural boundaries of the fiber strand.
- 2. Attributive blending-This indicates the extent of interaction of different fiber attributes within the characteristic boundaries of the fibrous assembly.
- 3. Appearance blending-This describes the extent of homogenization of color or component apparent intensity in the fiber assembly.
- 4. Interactive blending-This implies the interaction between different fiber components during the blending process.

The importance of the above classification stems from the fact that each blending mode represents a different technological focus in the process of making blended textile products. Structural blending represents the foundation of any blending process since fibers of different types should be blended together according to some basic structural and geometrical criteria. This is the reason for the exclusive attention to this mode of blending reflected in previous studies. Attributive blending has always been assumed as a by-product of structural blending. In other words, if different fiber types are appropriately blended on the basis of the structural and geometrical criteria, attributive blending will be simultaneously achieved. One exception to this assumption that was realized by some investigators is the case of blending fibers of different strength properties [17, 34, 35]. Other exceptions will be discussed later in this study. In today's technology, there is an increasing trend toward technical textiles in which fibers are blended not only with substantially different fibers but also with different non-fibrous materials. This makes attributive blending a key issue that should be addressed with great deal of attention.

Appearance blending represents a uniquely different and challenging problem. As will be seen in the experimental analysis of this study, appearance blending can be independent of structural blending in many situations. In other words, meeting the structural criteria may not necessarily yield the anticipated appearance of a blended fiber strand. Accordingly, independent analysis should be used to evaluate appearance blending. Later in this study, we will discuss a number of innovative techniques to analyze appearance blending.

Interactive blending reflects the interactive nature between different fiber components and between fibers and machines. Different fibers will have different processing behavior depending on a number of factors including surface morphology and fiber resilience. When two or more fiber types exhibiting substantially different surface or resiliency characteristics are blended together, potential processing problems can occur. In addition to the impact of these problems on processing efficiency, they will likely influence the other modes of blending. Later in this study, we will discuss different methods to analyze interactive blending.

In the following sections, we discuss analytical aspects associated with the four blending modes. The merits of this discussion will become evident as we rationalize the experimental results of actual multi-component blends later in the study.

Structural Blending

In practice, structural blending is achieved by combining predetermined mass proportions of different fiber components together to form a fiber mixture. When many fiber components are processed together (e.g. many cotton bales), approximately equal proportions of fiber tufts are detached from the different bales and fed together to multi-mixing units for blending. In these units, tufts detached from different cotton bales are combined and re-combined through progressive doubling effect so that each bale in the laydown can have a representation in the mix cross-section [18]. In the context of fiber characteristics, the Micronaire reading, which is a measure of fiber fineness, is commonly used as the primary criterion of structural blending of cotton fibers. In other words, different cotton components (or bales) are blended together on the basis of pre-determined average Micronaire value. Fiber length is typically used as the second blending criterion. When cotton and synthetic fibers are blended together, fiber fineness in millitex or denier is typically used as the main blending criterion and fiber length becomes an essential second criterion. It is also important to account for the difference in bulk density of the fiber components in the blend [34].

Traditionally, evaluation of the performance of a structural blending process has been made through testing the irregularity in the thickness or the mass of the resultant yarn. This measure has been commonly accepted on the ground that high variability in the mass or thickness of the blended fiber strand can be partially attributed to high variability in the number of fibers per cross section or along the axis of the fiber strand. This variability is primarily caused by inconsistent arrangement of the fibers that can be caused by variability in fiber fineness and/or fiber length or by process-added variability such as mechanical defects.

In practice, however, a direct relationship between yarn irregularity and the variability in the structural characteristics of the fibers is hardly established except for extreme cases in which inconsistency in the fiber mix is grossly induced [7, 15]. Furthermore, when the issue of concern is blending efficiency, or the extent of representation of a certain fiber component in the blend in proportional to its amount in the input material, no practical measures are available to determine this critical parameter.

The main criteria of structural blending are: the variability in the number of fibers per yarn cross-section and along the yarn, and the extent of representation of a certain fiber type in the blended fiber strand. The first criterion represented the primary focus of most previous investigations of fiber blending. In this regard, most investigators used the traditional axiom that the best processing machinery can do in the preparation of spun yarns is to arrange fiber ends in a random order [2, 3, 21, 22, 24, 25, 26]. Using this axiom, Martindale [22] assumed a Poisson distribution to model the randomness of number of fibers per cross-section. This assumption resulted in Martindale's familiar equation:

$$\sigma_n = \sqrt{\bar{n}} \qquad or \qquad C.V\% = \frac{100}{\sqrt{\bar{n}}} \tag{1}$$

where σ_n is the standard deviation of the number of fibers per cross-section, and *n* is the average number of fibers per cross-section. C.V% is the coefficient of variation of the number of fibers per cross-section.

Other theoretical treatments of the variability in the number of fibers per yarn cross-section [2, 3, 24-26, 31-34] took into account 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. Obviously, one should also assume a practical lower limit since any spun yarn must consist of a minimum number of fibers per cross-section to maintain its continuous coherent. Some of these treatments used a binomial approximation to model the variability in the number of fibers per cross-section leading to the following equation [2, 3]:

$$\sigma_n = \sqrt{\bar{n} \left(1 - \frac{\bar{n}}{n_{\max}} \right)} = \sqrt{\bar{n} q}$$
⁽²⁾

where n_{max} is the maximum number of fibers per cross-section, $n = n_{max}$ p is the average number of fibers per cross-section, p is the binomial probability, and q = 1- p.

The analysis discussed above is suitable for mono-component blending or mixing of fiber components of the same type. When different fiber types are blended together, the same analysis can be extended to account for the variability of the number of fibers in each fiber type. Coplan and Klein [2] analyzed the case of two-component blends using the binomial approximation discussed earlier. According to this analysis, suppose that the two fiber components blended together is W and B. The variability in the number of fibers in the W-type component and the B-type component is determined respectively by the following equations:

$$S_{W_i} = \sqrt{n_i pq}$$

$$S_{B_i} = \sqrt{n_i pq}$$
(3)

where p is the proportion of the W-type fiber in the blend, q is the proportion of the B-type fiber in the blend, and $n_i = W_i + B_i$.

Over a finite yarn segment, the probability of finding a given kind of fiber will depend on the sum of lengths of that kind of fiber. Accordingly,

$$\frac{p}{q} = \frac{\sum_{i=1}^{w} L_i}{\sum_{j=1}^{b} L_j}$$
(4)

where L_i = length of ith W-type fiber, L_j = length of ith B-type fiber, w = the total number of W-type fibers, b = the total number of B-type fibers.

The second criterion of structural blending is the extent of representation of a certain fiber type in the blended fiber strand. Previous investigations [3, 29] dealt with this criterion on the basis of the probability of the presence of a particular fiber component in the strand cross section. In this study [15], the probability of existence of a particular fiber component in the blend was expressed as a function of the geometrical properties of the fiber component considered. The general expression of this probability, termed 'representation index, RI', is as follows [15]:

$$RI_{f_i} = p(f_i \mid (f_1, f_2, \dots, f_k) = p(\frac{n_i}{n}) = \phi(\frac{L_{f_i} \times F_{f_i}}{\rho_{f_i}})^{-1}$$
(5)

where f_i is the event of existence of a certain fiber component f_i given that other fiber components in the blend, f_1, f_2, \ldots, f_k are also present in the cross section of the fiber strand, n_i is the number of fibers of fiber component i, and n is the total number of fibers per cross section.

The above expression indicates that fiber components of short, fine and high density fibers will have greater chance of being represented in a random cross section of a blended fiber strand than those of long, coarse and low density fibers. This is expected on the ground that shorter and finer fibers have greater representation by number in a proportionally-weight allocated blend.

Attributive Blending

One of the main reasons of fiber blending is to produce a fiber mixture of pre-determined average values of fiber characteristics that cannot be found in only one type of fibers. In this case, the focus should be on attributive blending. As indicated earlier, attributive blending is characterized by the extent of interaction of different fiber attributes within the characteristic boundaries of the fibrous assembly. In this study, we evaluate attributive blending using three approaches: visualization of the blending matrix, evaluation of blend profiles, and evaluation of characteristic probability distribution. The principles of these approaches are discussed below.

The interactive attributive nature of fiber characteristics in the blend can be visualized using a blending matrix, which consists of m rows describing the values of different fiber attributes and k columns describing the different components in the blend. At each blend ratio, the outcome of the blend can be described by a column vector matrix indicating the resultant values of different fiber attributes in the blend at a given blend ratio. Example of the general form of a blending matrix is as follows:

$$Z = \begin{cases} 1 & 2 & \dots & i & \dots & k \\ FS_1 & FS_2 & \dots & FS_i & \dots & FS_k \\ FL_1 & FL_2 & \dots & FL_i & \dots & FL_k \\ Fin_1 & Fin_2 & \dots & Fin_i & \dots & Fin_k \\ \dots & \dots & \dots & \dots & \dots & \dots \\ Rd_1 & Rd_2 & \dots & Rd_i & \dots & Rd_k \end{cases} = \begin{cases} B_j \\ FS_{Bj} \\ FL_{B_j} \\ Fin_{B_j} \\ \dots \\ Rd_{B_j} \end{cases}$$
(6)

where FS_i, FL_i, Fin_i, and Rd_i are fiber strength, fiber length, fiber fineness, and color reflectance of component i in the blend. FS_{Bi}, FL_{Bi}, Fin_{Bi}, and Rd_{Bi} are the same fiber properties at a certain blend ratio.

In practice, attributive blending has been largely considered as a by-product of structural blending. In other words, fiber components blended by mass proportions, are assumed to exhibit characteristic values that are linearly proportional to the

blend ratio. It is important therefore that we evaluate the additivity and the linearity features of the blend. We perform this evaluation using the so-called "Blend Profile". This can be developed using a two-dimensional graph in which the x-axis is the blend ratio or the percent of one fiber component in the blend and the y-axis is the percent attributive representation, or the percent change of the value of a fiber attribute of one fiber component with respect to the value of the other component. Blend profiles are suitable for two-component blends. When more than two fiber components are used in the blend, other types of blend profiles can be used as will be discussed in Part II of this study.

As shown in Figure 1, a two-component blending profile allows simultaneous evaluations of many fiber attributes not only for the magnitude and direction (increase or decrease) of change at different blend ratios. Note that at 100% of one fiber component, say component A, the values of all fiber attributes of this component are all normalized to 100. In other words, if property I of component A exhibits a value of, say 4.0, this will be treated as 100. If component B has a property I value of 6, the percent difference will be 50%, and property I at 100% of component B (or 0% of component A) will be 150%. The same procedure is followed for different values of the property obtained at different blend ratios. This type of profiles will be used later in this study to evaluate actual two-component blends.

As indicated earlier, the blend profile can reveal two basic criteria of a two-component blend: additivity and linearity. According to the additive rule, the values of a certain characteristic at different blend ratios should fall between those of the two fiber components. In Figure 1, properties I, II, and III meet the additive criterion of the fiber blend. When the blend profile crosses the 100% baseline, the additivity rule is violated (e.g. property IV in Figure 1). This violation implies that at some blend ratio, the characteristic value of the fiber blend was either lower or higher than the corresponding values of the individual components. Typically, a failure of meeting the additivity criteria may result from some physical phenomena associated with the blend or from high with-component variability. In Part II of this study, these points will be demonstrated using actual fiber blends.

When the percent of one fiber component is increased in the blend the characteristic of the resultant blend should correspond to this increase in additive fashion by an increase or a decrease in the fiber characteristic. The expected relationship between the blend characteristic and the blend ratio should be linear (e.g. Properties I and II of Figure 1). However, a nonlinear relationship may exist due to a number of reasons including: poor blending, physical bias in the characteristic to one of the two components, violation in the additive rule, or high variability in the characteristic value. Again, these points will be addressed in Part II of this study.

When two-component blends of different fiber types are used, it will be useful to investigate the extent of linearity using quantitative measures. Statistically, the extent of linearity is best determined from the value of standard error of the estimate of the percent of a certain fiber component in the blend in relation to the fiber or yarn characteristic under consideration [6, 15]. To illustrate this point, consider the case of two component blend of type A and type B fiber. In this case, a linear profile of a certain fiber or yarn characteristic of this blend will be represented by the following general equation:

$$y = b_o + b_p p_A(\%) \tag{7}$$

where y is the fiber or yarn characteristic under consideration, $p_A(\%)$ is the percent of one fiber component (say, type A) in the A/B fiber blend, b_o is the intercept of the linear relationship, and b_p is the slope associated with the change in y with the percent of fiber A in the blend.

The slope b_p is the key estimate determining the extent of linearity in a blending profile. In simple regression analysis, testing the significance of the value of this estimate determines the extent of linearity in a relationship. In this regard, the following test of hypothesis is established:

H_o: $\dot{b}_p = 0$ (there is no linear relationship) H₁: $\dot{b}_p \neq 0$ (there is a linear relationship)

This hypothesis is tested using the familiar t-statistic [6]:

$$t = \frac{b_p - \beta_p}{s_{b_p}} \tag{8}$$

The term s_{b_p} is the standard error of the slope. A very low value of this standard error will result in rejecting the above null hypothesis, which implies a linear relationship. Different extents of linearity will be associated with different values of standard error in such a way that the smaller the standard error, the better the linearity. Later in this study, we will show how this quantitative measure is used to examine the extent of linearity in blending profiles.

The third approach used to evaluate attributive blending is the evaluation of the probability distributions of fiber attributes of the individual fiber components and the blended assembly. Any fiber component will exhibit a unique probability distribution of any of its fiber characteristics. Such distribution can be characterized by few statistical parameters such as the mean, the variance, the skew, the kurtosis, and the mode [6]. When different fiber components are blended together, the resultant fiber blend will also exhibit a probability distribution of fiber characteristic which reflects the structural and attributive nature of blending. According to the central limit theorem, a completely randomized blending should yield a Gaussian distribution of the blend fiber characteristic regardless the shape of distributions of the characteristics of individual components [6]. Therefore, a deviation from this distribution can be used as an index of non-randomness or bias in attributive or structural blending.

Figure 2 illustrates the above concept for a four-component blend. Typically, one of three main outcomes can result from blending different fiber components:

- A skewed distribution implying the superiority of a certain characteristic of one or more fiber components to the other components in the blend
- A bi-modal or multi-modal distribution implying a substantial separation of the values of fiber attributes or possible fiber clustering
- A smooth normal distribution implying a homogenous blend and a continuous overlapping of the characteristics of the different components in the blend

In light of the above discussion, it is important to evaluate the extent of variability at different blend ratios through examination of corresponding probability distributions. When blends are made from two different fiber types, it will be important to make such evaluation in reference to an ideal probability distribution of the blend. This ideal distribution can be generated on the basis of the assumption of complete random arrangement of fibers in the blend under conditions where the value of the fiber characteristic of one fiber component is independent from the value of the same characteristic of the other fiber component [6]. In this case, a normal probability distribution can be assumed to represent the ideal blend:

$$f(x) = \frac{1}{\sigma_R \sqrt{2\pi}} e^{-\frac{(x-\mu_B)^2}{2\sigma^2}} \qquad -\infty \le x \le \infty$$
(9)

where the mean $\mu_{\rm B}$ and the standard deviation $\sigma_{\rm B}$ of the distribution are determined from the following formula:

$$\mu_{B} = \sum_{i=1}^{k} \alpha_{i} \mu_{i} \quad \& \sigma_{B}^{2} = \sum_{i=1}^{k} \alpha_{i}^{2} \sigma_{i}^{2}$$

where α_{i} is the proportion of fiber component i in the blend and μ_{i} and σ_{i}^{2} are the mean and the variance of the fiber characteristic of component i in the blend. We should point out that the proportion α_{i} used in the above equation represents the amount of a certain fiber component in the blend by-number, not by-weight.

The significance of developing an ideal probability distribution stems from the possibility to develop an index of blending efficiency based on comparative analysis between the actual frequency distribution of a fiber characteristic at a certain blend ratio and the corresponding ideal probability distribution. In this regard, we propose two blending indices: (1) Signal Blending Index (SBI), and (2) Noise Blending Index (NBI). These two indices reflect two possible types of departure from ideal blending. The first type is a shift in the mean value of the actual blend from the ideal blend at an extent of variability equivalent to the random variability in the ideal blend. The second type is a change in variability at a mean value equivalent to that of the ideal blend. These two types of shift are demonstrated in Figure 3 and they are discussed below.

The Signal Blending Index (SBI) indicates the extent of agreement between the actual blend probability distribution and the ideal blend probability distribution when a shift in the mean value of the actual blend from the ideal blend occurs at an extent of variability equivalent to the random variability in the ideal blend. Accordingly, the SBI is defined by the following expression:

$$SBI = p\{x_L \le x_a \le x_U \mid (\mu_{IB} - \mu_{aB}) = \delta\sigma\}$$
(10)

where x_L and x_U are the lower and upper natural limits of the ideal probability distribution of a blend fiber characteristic, x_a is a random variable representing the value of the fiber characteristic of the actual blend, μ_{IB} is the mean of the ideal blend distribution, μ_{aB} is the mean of the actual blend distribution, σ is the standard deviation of the blend characteristic, and δ is the magnitude of signal shift.

In order to demonstrate how the SBI is determined, suppose that the natural variability in a fiber characteristic of an ideal blend probability distribution spreads over a range of $2z\sigma$ as shown in Figure 4. This means that the lower and upper natural limits of the ideal probability distribution are (μ_{IB} - $z\sigma$) and (μ_{IB} + $z\sigma$), respectively. Also suppose that the actual probability distribution of the fiber characteristic of the blend suffers a signal shift of " $\delta \sigma$ " from the ideal mean value. In this case, the SBI will represent the area under the curve of the actual blend characteristic that falls within the natural limits of the ideal probability distribution (i.e. the shaded area of Figure 4).

At different signal shift values, $\delta\sigma$, from the ideal mean, different SBI values can be obtained from the Standard Normal Table [6]. In Table 1, SBI values expressed in percent are listed at different signal shift values. The SBI can be calculated for any fiber characteristic of two-component or multi-component blends.

The Noise Blending Index (NBI) indicates the extent of agreement between the actual blend probability distribution and the ideal blend probability distribution when the actual distribution suffers variability larger than that of the ideal blend distribution at a mean value equivalent to that of the ideal blend. This index can be determined from the following expression:

$$NBI = p\{\sigma_{aB} \approx \sigma_{IB}\} = p\{x_L \le x_a \le x_U \mid (\sigma_{aB} \ne \sigma_{IB})\}$$
(11)

where x_L and x_U are the lower and upper natural limits of the ideal probability distribution of a blend fiber characteristic, x_a is a random variable representing the value of the fiber characteristic of the actual blend, σ_{IB} is the standard deviation of the ideal blend distribution, and σ_{aB} is the standard deviation of the actual blend distribution.

The two blending indices discussed above represent two different possibilities that often occur in practice. When both signal and noise shifts occur simultaneously, we can still determine the two blending indices independently. However, the values of the two indices may become highly dependent. In other words, the value of one index may depend on the other. In this case, it will be important to interpret the values of the two indices in view of the extent of overlap of the signal and noise shift.

Appearance Blending

As indicated earlier, appearance blending describes the extent of homogenization of color or component apparent intensity in the fiber assembly. Similar to attributive blending, appearance blending has been treated as a by-product of structural blending. Typically, components of different color or shade intensity will yield additive color or shade when they are blended together. However, the color intensity of the blended fiber assembly may not follow a linear trend with the structural blend ratio even on a by-number scale. This fact was realized in early investigations. Typically, if one were to blend otherwise identical black and white fibers on present-day machinery the best possible blend would contain some grouping together of whites and also grouping together of blacks [10, 21]. Our experience confirms that even with today's multi-mixing processes, the best that can be expected is a random clustering of different colors in the cross-section of the yarn. This means that distinct colors may appear along the yarn surface in such a way that some segments or some cross-sections of the yarn will be predominantly of one color.

Traditionally, appearance blending has been analyzed subjectively through visualization of the appearance of the blended fiber strand. Later in this study, we will discuss a new objective approach based on image processing and analysis of color intensity.

Interactive Blending

As indicated earlier, interactive blending implies the interaction between different fiber components during the blending process. It can be measured by the extent of reducing fiber clumps down to single fibers during the blending process. Examination of fiber flow during processing reveals that fibers do not flow in single-fiber form. Instead, fibers tend to aggregate and flow in groups of few fibers. An extreme case of this aggregation may result from a processing failure to breakdown large aggregates of fibers due to some form of excessive inter-fiber bonding such as high inter-fiber friction, high crimp, or static charges.

The importance of interactive blending stems from the fact that it can impact all other modes of blending. Two fiber types that are perfectly mixed together on the basis of structural criteria may yield extremely non-linear blending patterns as a result of what we term "fiber propensity divorce", or the lack of interactive compatibility between the two fibers. This situation often occurs when fibers of different surface characteristics (e.g. cotton and polyester fibers) are blended together. Unfortunately, the application of optimum spin-finish and anti-static or lubricant treatment is still a work of art. Fiber propensity divorce can also occur for blends of the same type of fibers. For example, mixing two cottons of extremely different preparation (i.e. saw-ginned with roller-ginned cotton, or normal cotton with sticky cotton) can result in poor interactive blending.

In theory, interactive blending was evaluated by considering the variability in the number of fibers per yarn cross-section in situations where clusters of fibers are present in the blend. Coplan and Klein [2] introduced a parameter, C, representing the average number of fibers per cluster. The number of clusters in a cross-section of a maximum number of fibers is n_{max}/C , and

the average number of clusters in a cross-section is n/C. This will lead to the same value of probability, p as determined by:

$$p = \left(\frac{\bar{n}/C}{n_{\max}/C}\right) = \frac{\bar{n}}{n_{\max}}$$
(12)

Using the binomial approximation discussed earlier, the standard deviation of the number of clusters in randomly selected cross sections is

$$\sigma_{C} = \sqrt{(n_{\text{max}} / C)pq} = \sqrt{\bar{n}q / C}$$
(13)

The number of individual fibers will be C times the number of clusters. Thus,

$$\sigma_n = C\sqrt{\bar{n}q/C} = \sqrt{\bar{C}nq} \tag{14}$$

The clustering factor, C, can be 1 or anything greater.

In light of the above analysis, a key issue is to evaluate how effectively the blending process has reduced the feed-stocks of fibers to single-fiber components. From the above equation, the average number of fibers per cluster, C, can be expressed as follows:

$$C = \frac{\sigma_n^2}{\bar{n}.q} \tag{15}$$

This equation cannot be solved without knowledge of q.

In a latter Part of this study, we will discuss a new experimental technique for measuring the extent of breakdown of fiber clusters in the blend. This technique is based on measuring the propensity for opening and blending of the different fiber components in the blend. The analysis associated with this technique represents an extension of an earlier study by El Mogahzy et al [11, 12].

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Table 1. SBI Values at Different Signal Shifts.	
Signal Shift Value (δσ)	SBI Values
0.5 σ	99.4%
1.0 σ	97.7%
1.5 σ	93.3%
2.0 σ	84.1%



Figure 1. Blend profiles of Different Fiber Attributes (Fiber Types A and B).



Figure 2. Possibilities of Attributive Blending Outcome at Equal-Proportion Blends.



Figure 3. Illustration of Signal Noise Shifts from the Probability Distribution of Ideal Blend.



Figure 4. The Concept of Signal Blending Index (SBI) at Mean shift of $\pm \delta \sigma$ and Natural Tolerance of $\pm z\sigma$.