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A Simplified Optimization in Cotton Bale Selection and Laydown

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Abstract : We present a new approach to bale laydown grouping, which improves the laydown to laydown uniformities, compared to conventional approaches. In this approach, we use a frequency-relative picking method based on an HVI quality index for cotton bale selection and laydown formation. We demonstrate the effectiveness of this approach by computer simulation on real HVI data of 1500 cotton bales. Simulation results show that the proposed method significantly outperforms random picking.

Introduction

Recent development of HVI (High Volume Instrument) system for cotton testing is considered to have had significant impact on the technology of textile manufacturing and the economics of cotton marketing, sales, and distribution. According to the growing demand for HVI-based cotton fiber properties, most cotton bales are now stored, retrieved and formed into laydowns based on HVI measures. Consequently, an optimal blending method of cotton bales is needed not only to produce good quality products, but also to use cotton bales efficiently and thoroughly as possible during the production process.

In order to make the qualities of textile products uniform and manage the cotton bales efficiently, the two most important objectives for every cotton spinning mill are (*a*) to select cotton bales meeting the quality requirements of yarns and fabrics at a given level of raw material cost; and (*b*) to make the laydown averages with respect to fiber strength, micronaire, length and occasionally other characteristics, as uniform as possible across daily and weekly shifts.

In order to achieve the first objective, many attempts[1-5] have been made in selecting cotton fibers. Lee *et. al*[1] and Morgazy[2] suggested trial-and-error methods by using linear programming for optimizing cotton mixing ratios based on weight that satisfy the constraints such as fiber length, fineness, strength, and cost. In the following study by Morgazy[3], a fiber quality index[6] and yarn strength were used as constraints for optimizing cotton blend costs using linear programming. The methods using linear programming can provide tools for selecting cotton blend components under inventory and quality constraints. However, the second objective cannot be tried to be satisfied with the above methods.

The objective of this paper is to equalize the averages of HVI properties laydown to laydown within a time period that matches the inventory of the available cotton bales. Statistically, this method is intended to minimize the local between-laydown variances for more than one cotton characteristic simultaneously.

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Relationship between Within- and Between-Laydown Variances

Suppose we have N bales in the warehouse to form k laydowns and each laydown has n bales. As the objective is concerned with variances of the bale characteristics, it is necessary to analyze the variance structure. Let $\bar{y}_i$ be the ith laydown mean of characteristic y, $\bar{\bar{y}}_i$ be the grand mean of characteristic y, σ_t^2 be the total variance of characteristic y, $\sigma_{w_i}^2$ be the within-laydown variance of ith laydown, σ_w^2 be the mean of within-laydown variances of all laydowns, σ_b^2 be the variance of laydown means or between-laydown variance of all laydowns, and y_{ij} be the value of jth bale in the ith laydown. Then we can easily obtain the following variance components from HVI data

$$\bar{y}_i = \frac{1}{n}\sum_{j=1}^{n} y_{ij}, \quad \bar{\bar{y}} = \frac{1}{kn}\sum_{i=1}^{k}\sum_{j=1}^{n} y_{ij}, \tag{1}$$

$$\sigma_t^2 = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(y_{ij} - \bar{\bar{y}})^2}{(N-1)}, \tag{2}$$

$$\sigma_{w_i}^2 = \frac{\sum_{j=1}^{n}(y_{ij} - \bar{y}_i)^2}{(n-1)}, \tag{3}$$

$$\sigma_w^2 = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(y_{ij} - \bar{y}_i)^2}{(N-k)}, \tag{4}$$

$$\sigma_b^2 = \frac{\sum_{i=1}^{k}(\bar{y}_i - \bar{\bar{y}})^2}{(k-1)}. \tag{5}$$

Using the additive properties of the sum of squares in the analysis of variance (ANOVA), we obtain the total sum of squares, TSS, by adding the sum of squares for laydowns, SSTR, and the error sum of squares, SSE, as follows:

$$TSS = SSTR + SSE,$$

$$(N-1)\sigma_t^2 = (N-1)\sigma_w^2 + (N-n)\left(\sigma_b^2 - \frac{\sigma_w^2}{n}\right). \quad (6)$$

From equation 6, we have the linear relationship between σ_w^2 and σ_b^2 as follows:

$$(N-1)\sigma_t^2 = (N-k)\sigma_w^2 + (N-n)\sigma_b^2,$$

$$\sigma_w^2 = \frac{(N-1)}{(N-k)}\sigma_t^2 - \frac{(N-n)}{(N-k)}\sigma_b^2 = -a\sigma_b^2 + b. \quad (7)$$

From Equations 6 and 7, the total variability in a fiber characteristic is constant. If the bales are picked randomly from a bale population, a reduction in between-laydown variance (σ_b^2) will result in a systematic increase in the mean of within-laydown-variance (σ_w^2), and vice versa. Therefore, our task is to find a systematic picking method in which the between-laydown variance (σ_b^2) is as small as possible and the within-laydown variance ($\sigma_{w_t}^2$) is expected to be consistent in a laydown-to-laydown basis.

Bale Selection and Laydown Formation Practices Based on HVI Data

HVI characteristics of 1500 cotton bales were obtained in a two-week period in an unidentified textile mill. In order to form laydowns, a bale selection program was developed using Perl language including the following steps: (1) The important HVI characteristics were selected for laydown formation. (2) The number of bales for each laydown was determined to optimize within- and between-laydown variances. (3) Based on the HVI characteristics, the laydowns were formed in such a way that the between laydown variances (σ_b^2) of more than one HVI characteristics could be minimized simultaneously under a technically sustainable level of the within-laydown variance.

Formation of Fiber Quality Index Using Intrinsic Fiber Characteristics for Laydown Formation

The fiber characteristics currently measured by the HVI system include: fiber length, length uniformity, short fiber content, micronaire, strength, elongation, reflectance (R_d), yellowness ($+b$), and trash content. In order to form laydowns, it is not necessary to deal with every characteristic. Only "a vital few" can be selected as intrinsic fiber characteristics for laydown formation. The definition of an intrinsic characteristic is a measurable or countable fiber characteristic, which is imbedded in yarn structure in such a way that it intrinsically influences yarn and fabric properties. To represent yarn tensile properties, the fiber length (FL), strength (FS) and micronaire (MIC) were selected as intrinsic fiber characteristics. A summary of statistics is given in Table 1.

Table 1. Summary of HVI properties

HVI Properties	Statistics
Micronaire (μg/inch)	Mean = 3.58 S. D. = 0.52 C. V. (%) = 14.53
Strength (gf/tex)	Mean = 28.43 S. D. = 1.94 C. V. (%) = 6.82
Length (inch)	Mean = 1.096 S. D. = 0.04 C. V. (%) = 3.65

In order to optimize the between-laydown variances of three characteristics, simultaneously, we have used a composite index called "HVI Quality Index (HQI)". The HQI combines the important fiber characteristics in such a way that it can be shown to have a maximum correlation with the yarn quality or processing performance. The HQI were formed based on the HVI strength, length and micronaire as follows:

$$\text{HVI Quality Index (HQI)} = (FS \times FL)/MIC. \quad (8)$$

The HQI was used as an experimental factor for forming laydowns in order to optimize the between-laydown variance.

Determination of Optimal Number of Bales per Laydown

Based on Equation 7, the relation between the between- and within-laydown variances depends on the number of bales per laydown (n) with the fixed total number of bales

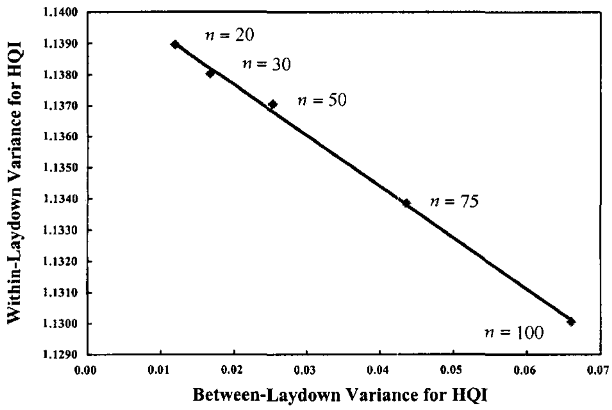

Figure 1. Linear Relationship between Within- and Between-Laydown Variances (N=1500).

(N) in the warehouse. Therefore, our task is to find the number of bales per laydown, in which the between- and within-laydown variances take the middle values. This means that we can avoid a case in which either of the variances have the extreme values.

The k laydowns were formed with n bales (n = 20, 30, 50, 75, 100) randomly selected out of 1500 bales each. This experiment was repeated 25 times. The average between- and within-laydown variances for HQI were calculated. Figure 1 shows the effects of the number of bales per laydown on between- and within-laydown variances for HQI. The between-laydown variance decreases and within-laydown variance increases as n increases. It was found that the both variances take middle values when n is 55~75 bales with respect to HQI.

Bale Picking based on Frequency Distribution of HVI Quality Index (HQI)

A reliable bale picking scheme should result in a consistent average of fiber characteristics on a laydown-to-laydown basis. In this study, we compare two different bale selection and laydown formation schemes:random picking (RP) and frequency-relative picking (FRP) schemes. In a random picking scheme, bales are picked randomly from the parent bale population (the warehouse). By definition, any value of the fiber characteristic (or any bale) in the population will have the same opportunity to be represented in bale laydown. In frequency-relative picking, cotton bales belonging to a certain class should represent in the laydown in numbers proportional to the relative frequency in the population. The number of bales picked from each class is decided by Equation 9,

$$n_j = n \times \frac{N_j}{N} \tag{9}$$

where n_j is the number of bales picked from the jth class in a laydown, n is the number of bales in a laydown, N_j is the number of bales in jth class and N total number of bales in warehouse.

In order to form the laydowns using FRP, the frequency distribution of HQI was shown in Figure 2. The range of HQI was divided into 12 classes and then n_j was calculated using Equation 9. Considering the results in Section C, 60 bales were planned to be selected to form 25 laydowns. Because n_j must be an integer, only 54 bales were picked for each laydown instead of 60 bales. Therefore, only 1350 bales were used for laydown formation.

In Figures 3~6, FRP is compared against the RP for laydown averages and within-laydown variances of HQI and micronaire. The between-laydown variance (σ_b^2) and the mean of within-laydown variances (σ_w^2) are also given in Table 2. The results show that the FRP is definitely superior to the RP scheme on both the laydown-to-laydown uniformities of the averages and within-laydown

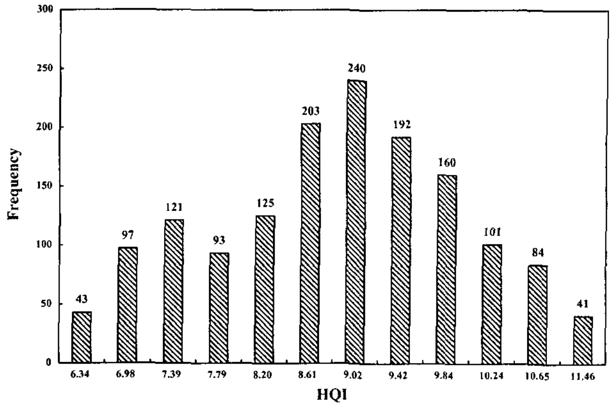

Figure 2. Frequency Distribution for HQI.

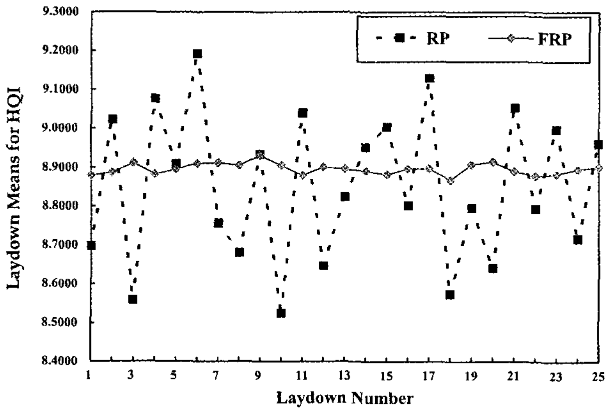

Figure 3. Comparison of Laydown Means for HQI (n = 54, k = 25).

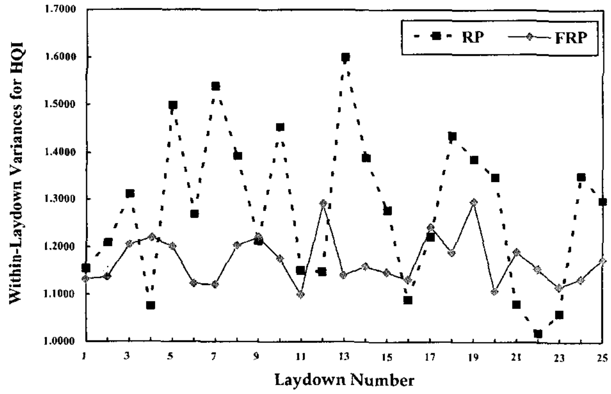

Figure 4. Comparison of Within-Laydown Variances for HQI (n = 54, k = 25).

variance for HQI and micronaire. More importantly, the within-laydown variances under FRP are shown to be not only small but also uniform across all laydowns in Figures 4 and 6 and Table 2. This contradicts the claim given in Equation 6, which shows that σ_w^2 increases as σ_b^2

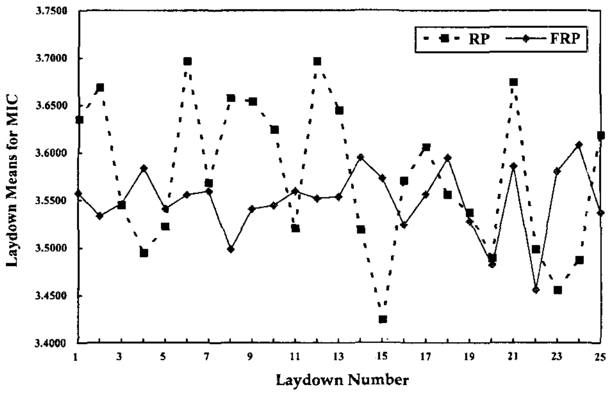

Figure 5. Comparison of Laydown Means for Micronaire (n = 54, k = 25).

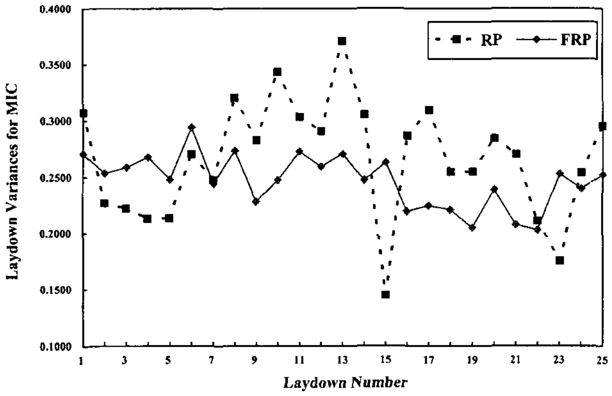

Figure 6. Comparison of Within-Laydown Variances for Micronaire (n = 54, k = 25).

Table 2. Comparison between FRP and RP methods

	Laydown Method	σ_w^2	σ_b^2
HQI	FRP	1.1721	0.0002
	RP	1.2787	0.0363
MIC	FRP	0.2467	0.0012
	RP	0.2665	0.0063

decreases. This causes that we selected only 1350 bales for the simulation from 1500 bales and 150 bales were left in the warehouse. Under FRP, more than half of the remaining bales are at the extreme end classes because number of bales picked from each class should be integer. Therefore, the σ_w^2 might be also reduced. The figures and the table clearly demonstrate the usefulness of applying the FRP for bale selection and laydown formation.

The laydown averages of strength and length under FRP are not shown in figures. The between-laydown variances of FRP are, however, shown to be smaller than those of RP for strength (RP = 0.31, FRP = 0.26) and length (RP = 0.0055, FRP = 0.0053). The reason for this is because the CV% of strength and length are much smaller than CV% of micronaire as shown in Table 1. This means that the FRP is more effective to minimize between-laydown variances for high variable population.

Conclusions

The newly developed bales selection and laydown formation method (FRP) have shown the following:

1. The maximum number of bales per laydown can be 55~75 bales to optimize both within- and between-laydown variances simultaneously.
2. The FRP with HQI is an effective and useful method in simultaneous reduction of more than one between-laydown variances corresponding to multi-characteristics aimed at optimizing the within-laydown variances.
3. The new method is even more effective at reducing the variances for highly variable population.
4. We conclude that this method can be simply and easily used for practical application in cotton mills.

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