Predicting Yarn and Fabric Properties
In Denim Manufacture

by

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Introduction

In an earlier work, I developed an economic model of yarn manufacture which relied on regression equations developed form U.S.D.A spinning test data. The purpose of this paper is to describe the fitting of repression equations to data from an operational textile mill.

The repression equations relate the properties is the cotton fiber to the properties of the yarn and fabric made from the fiber. These equations give us the ability to predict the quantity and quality of yarn and textiles produced with any given cotton fiber feedstock.

Because methods of production vary widely between establishments, it is impossible to develop a set of equations which would be applicable to all mills. However, if should almost always be possible to develop a specific set of equations for an individual mill. The approach is to apply multiple regression analysis to quality Control data the mill already collects on a routine basis. The data collection and analysis can be performed with almost no interruption to the normal operation of the mill.

Model Development

Cotton Inc. arranged for a denim manufacturing establishment to act as a test site for the analysis. The manager provided time-series observations on the following variables for analysis:

Yarn property measurements:

(1) Thick places,

(2) Thin places,

(3) Yarn Neps,

(4) Yarn CV

(5) Elongation,

(6) Skein Break,

(7) Break Factor,

(8) Slubs, and

(9) Yarn Count.

Fabric property Measurement

(1) Weight, (original and washed,)

(2) Breaking Strength,

(3) Tear Strength,

(4) Elongation,

(5) Shrinkage, and

(6) Stiffness.

Fiber Properties:

(1) Uniformity,

(2) Micronaire,

(3) Length,

(4) Strength, and

(5) Elongation.

The source for the fabric and yarn data was tests performed by the plant's own quality control staff. The source for the fiber properties was the USDA fiber test data for each bale.

The data was organized chronologically, taking account of the lag in time between the fiber properties and the corresponding yarn properties, and the lag between the yarn properties and the corresponding fabric properties. The fiber and yarn data was also organized as to whether the observations were for warp or filling.

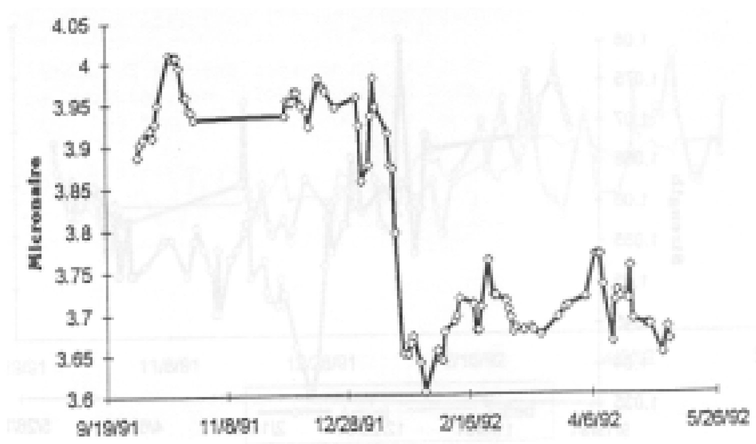
Separate warp and filling time series regressions were run for the fiber to yarn equation, but the fabric equations used variables from warp and filling properties of fiber and yarn.

Estimation Results

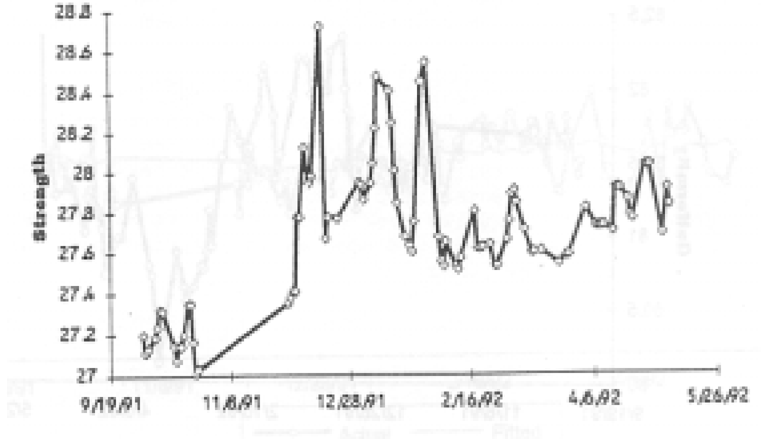
The results of the regressions have been mixed. R-squared statistics were typically around. 5-meaning that the regressions explain only about half of the variation in the dependent variable. Most t-Ratios were significant, but sometimes the sign of the corresponding regression coefficient would be contrary to expectation. In the fabric equations, there were only 12 (bi-weekly) observations. The small number of observations increases the probability of spurious correlation, and decreases the precision of the estimates. In the yarn regressions, there were between 80 and 100 observations, depending on the variables used. These regressions were characterized by higher t-ratios than the fabric regressions, but the R-squared statistics were about the some or lower.

It would be tedious to depict all of the regression equations in this paper, however as an example, consider the production of warp yarn. The following graphs how the properties of warp fiber input over the period covered by the data provided by the mill. The data displayed is a four day moving average of fiber inputs. The dates are offset by three days to represent the average lag between fiber input and yarn output.

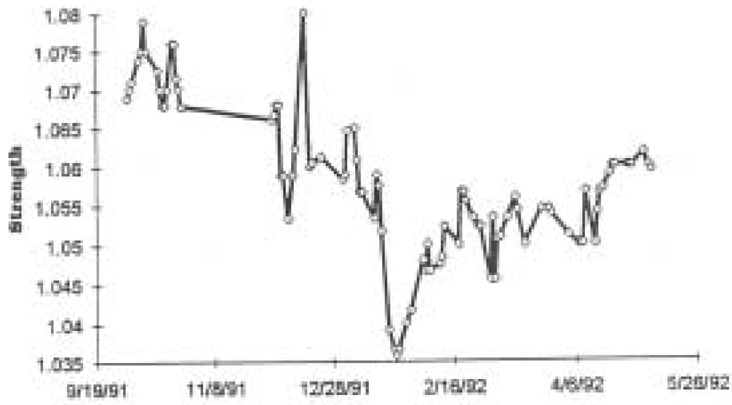
< Graph 1 > Warp Micronaire



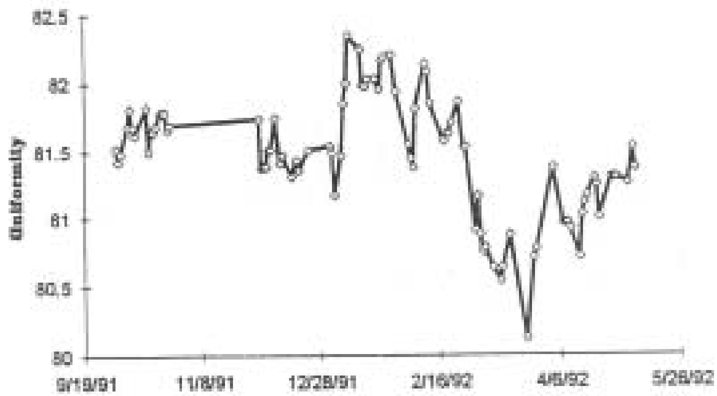
< Graph 2 > Warp Fiber Strength



< Graph 3 >Warp Fiber Length



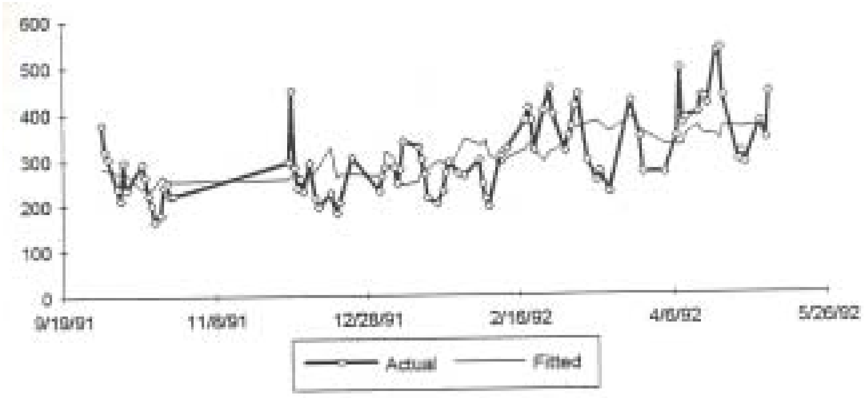
< Graph 4 > Warp Fiber Uniformity



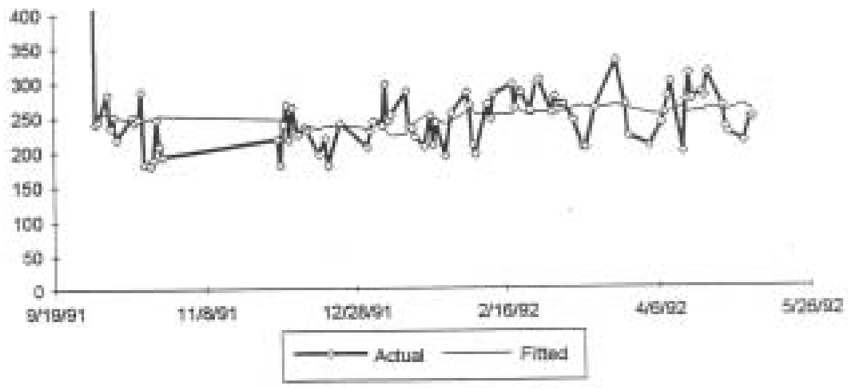
Note that in the middle of January there was a dramatic drop in Micronaire, and Micronaire stayed low after the drop. There was also a drop in length at around that time, buty the drop was not as dramatic, and there was a return to more usual values. The other fiber properties also show irregular paths over time.

One would expect the changes in fiber properties to induce corresponding patterns in the properties of the yarn made from these fibers. To see whether this is true, let us examine graphs of total NEPS, THICK places and THIN places, three of the yarn properties collected by the mill using on-line sensors.

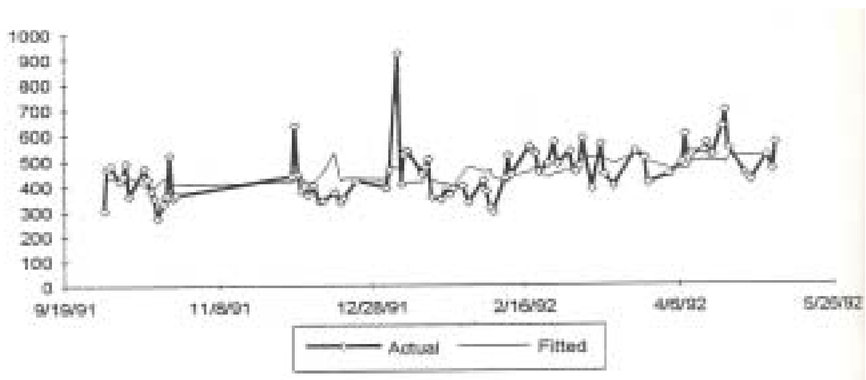
< Graph 5 > Total Warp Yarn Neps



< Graph 6 >Total Warp Yarn Thick Places



< Graph 7 > Total Thin Places Warp Yarn



In each of the preceding graphs, the "Actual" corresponds to the data in the spreadsheets provided by the mill. The "Fitted" data on the plot are predicted values from linear regressions based on the fiber properties.

Compared to the fiber properties. The yarn properties are essentially trendless. That is, here and there one may observe transient spikes in the data, but over the hold period, with the exception of Neps, the average level stays pretty much constant. For Neps, there is a slight upward trend for the second half of the graph. Since there is little trend in the yarn properties over time, and there are obvious trends in the fiber properties, it should come as no surprise that the fit of the regressions was rather loose.

The regression equations were of the following configurations:

TOT NEPS = A*Fiber Strength + B*Fiber Length + C*Fiber Micronaire

+ D*Fiber Uniformity + E

TOT THICK = F*Fiber Strength + G*Fiber Length + H*Fiber Micronaire + I

TOT THIN = J*Fiber Strength + K*Fiber Length + L*Fiber Micronaire + M

In these equations, the yarn properties are the dependent variables, The parameters A,B,C, ... K,L,M, which determine the strength and direction of the relationships, are unknown, but have been estimated by ordinary least squares.

The sole purpose of these equations is show whether and how changes in yarn properties can be determined by changes in fiber properties. For example, if Micronaire were to change by 1 unit, then TOT NEPS would change by 1*C units.

The equations were kept linear for the sake of simplicity. In earlier work, we used various alternative relationships including logarithmic transformations, polynomial functional forms (including first-order interactions), and reciprocal transformations, but because the domain of the independent variables is so narrow, it was found that functional form had little effect on fit or predictability.

As an example of how the regression works for warp TOT NEPS, consider the following equation, in which estimated parameter values have been substituted for the unknown parameters in the equations above.

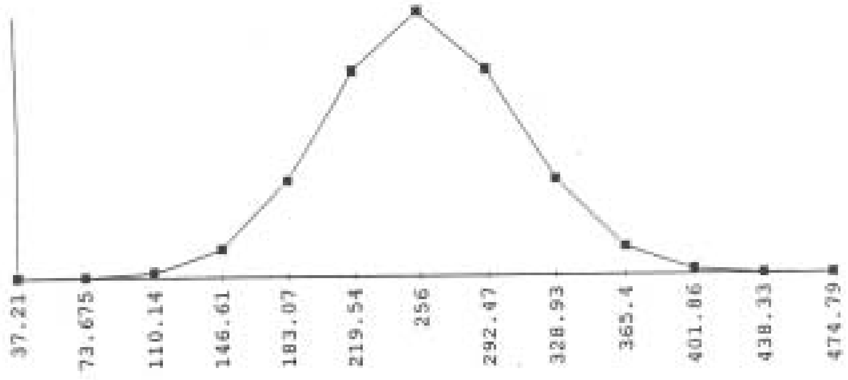
TOT NEPS = -44.5584*Uniformity - 304.875*Micronaire + 1716.28*Length + 29.82*Strength + 2289.25

The average values of warp fiber properties over the entire period were:

Uniformity	Micronaire	Length	Strength
81.69944	3.861763	1.058975	27.69938

Performing the indicated multiplications and additions, we obtain a predicted value for TOT NEPS of about 256. Furthermore, from advanced statistical methods not detailed here, we know the standard deviations of the estimate of TOT NEPS will be about 73. Given this data and the assumption that TOT NEPS will be normally distributed around its mean, we can predict that if we used an average bale of cotton, the distribution of TOT NEPS will take the following shape.

< Graph 8 > Distribution of Total NEPS in Warp Yarn



If we were to reduce Micronaire from 3.86 to 3.76, then the mean of the TOT NEPS distribution would fall from 256 to about 226.

Table 1 summarizes the results of the warp yarn regressions, showing the direction of influence of each fiber property on the three yarn properties.

Table 1. Summary of Warp Yarn Regressions

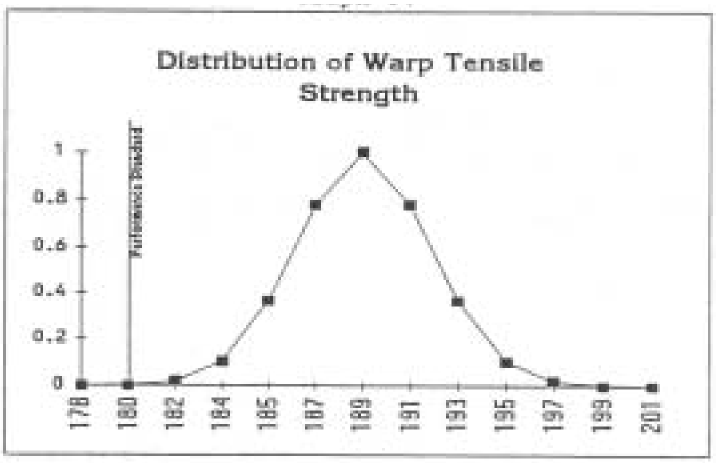
If .... increases	then	will ....
Fiber Strength	Totneps	increase
	Totthick	decrease
	Totthin	increase
Fiber Length	Totneps	increase
	Totthick	increase
	Totthin	increase
Fiber Micronaire	Totneps	decrease
	Totthick	decrease
	Totthin	decrease
Fiber Uniformity	Totneps	decrease
	Totthick	not change
	Totthin	not change

All of the yarn regression equations are similar in structure to the warp TOT NEPS formula. The fabric regressions are similar except that they include yarn properties as well as fiber properties, and they have fewer observations because yarn tests are made more often than fabric tests.

The quality of fit for these equations varies quite substantially. For example I could obtain no reasonable predictive equation for fabric stiffness. The explanatory power of the regressions, expressed as R^2, varied from a low of 03 for one of the yarn regressions to a high of . 90 for one of the fabric regressions. It would be desirable to obtain more observations in order to add precision to the estimates.

Using the estimated regression equations, one may predict hypothetical results for any potential combination of fiber inputs. For example, if all fiber properties for warp and filling are held constant at their average levels, we obtain following distribution for warp tensile strength :

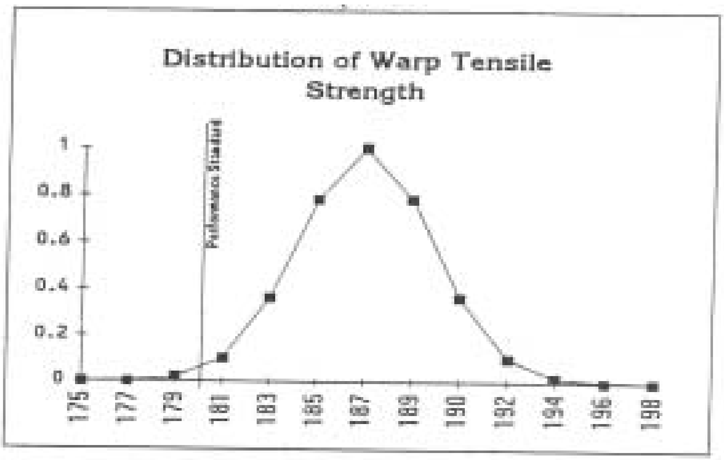
< Graph 9 >



Note that in this distribution, almost none of the production falls below the performance standard of 180 lbs.

If the warp fiber length is reduced from 1.059 to 1.055, then the new distribution for warp tensile strength looks like this:

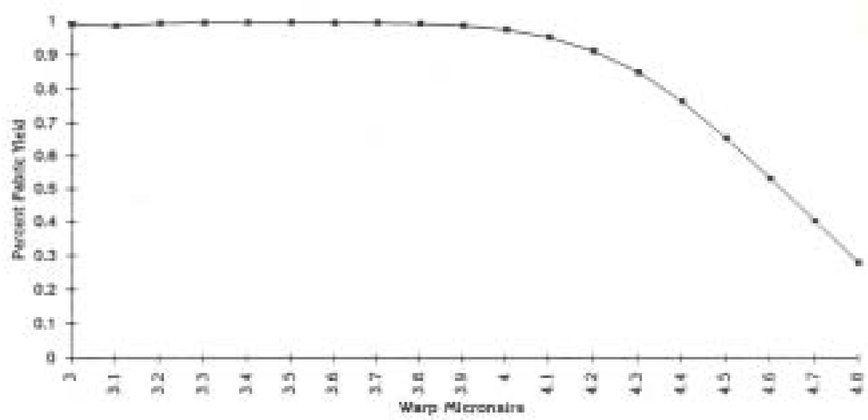
< Graph 10 >



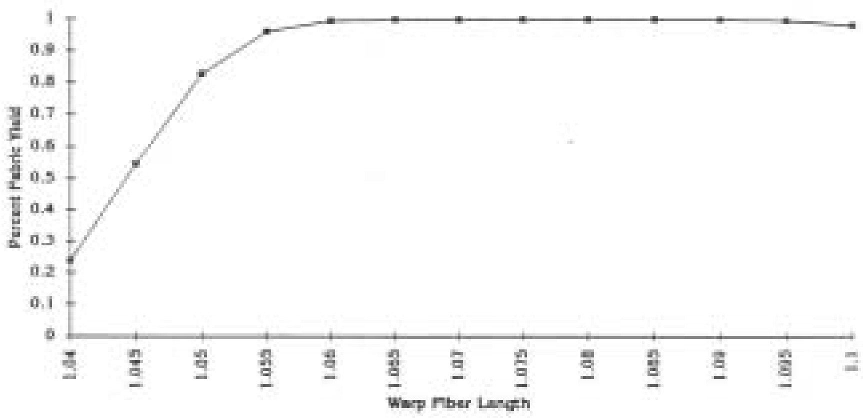
The mean of the distribution has fallen by about 2.5 lbs., and this has caused a larger part of the tail to fall below the performance standard. In the original regression, the amount of fabric lost below grade was negligible, but after reducing fiber length, the losses grew to almost four percent. In this illustration, a known decrease in fiber length induced an increase in the amount of production yield. Using the equation system in this way, we can predict the yield for any combination of input fiber properties.

The following graphs show the effects of changing various input fiber properties on the yield of above grade fabric.

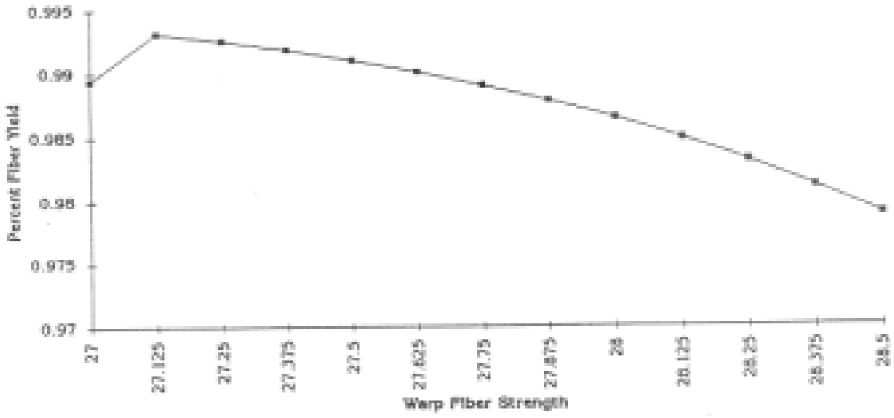
< Graph 11 > Effect of Warp Fiber Micronaire



< Graph 12 > Effect of Warp Fiber Length



< Graph 13 > Effect of Warp Fiber Strength



The above three results can be duplicated for the filling direction, but the results are not nearly as interesting-the yield is always 100%. Evidently, the properties of the filling fiber have little effect on the fabric losses, compared to the properties of the warp fiber.

Practical Implications

Preliminary work using the estimated regressions in this model suggests that even though the fit of the equations fairly loose, there is a potential profit gain from using the model to control cotton flow. Furthermore, it appears that the implementation of the model in an operational setting might be as easy as developing a simple set of rules, based on fiber properties, for sending a bale of cotton either to warp or filling. The rules would take the form of sets of conditions to assign all bales of specific length, strength and Micronaire ranges to warp, and other cotton to filling. As cotton inventory, price, and availability vary over time, the boundary between the warp and filling zones would change in response.

In the particular plant on which these regressions are based, our preliminary results suggest that the plant should avoid using cotton with a mike of over 3.8 for warp: it should avoid using fibers shorter than 1.055 for warp, and it should seek to use fibers in the 27 to 27.5 strength range for warp. Fiber that doesn't fit these specifications may be used for filling.