A NEW APPROACH TO PREDICTING COTTON YARN QUALITY ATTRIBUTES FROM FIBER CHARACTERISTICS USING UNIVERSAL EQUATIONS-PART II- UPDATE AND MERITS

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Introduction

Historically, the value of cotton fiber in the marketplace has been determined by basic fiber properties such as length and Mic as well as a number of attributes associated with trash level and preparation. Since 1980s, instrumental evaluation of cotton fibers using High Volume Instrument (HVI) has added speed, more consistency, and better acceptance of cotton quality values. In 1990s, the Advanced Fiber Information System (AFIS) was introduced, which added critical dimensions of quality evaluation, particularly with respect to processing performance. Today, utilization of these powerful systems has become a common practice in the textile industry around the world and numerous benefits associated with these systems have been realized from the cotton field to the end product. This realization can be illustrated in the following questions and answers.

- *Do we know today about fiber quality better than we did 20 years ago? Certainly*
- *Do we know enough to maintain a steady and consistent quality of yarns and fabrics? Certainly*
- *Can we truly say that today's knowledge has resulted in different approaches of manufacturing, maintenance, and management? To some extent*

Despite these great benefits, some key issues are yet to be resolved. These include:

- *Can we establish an objective measure (preferably in $$$) of the value of fiber quality information that has been generated by the advanced instruments? !!!!!*
- *What is the true value of fiber quality data? !!!!!*
- *How to maximize the $$$$ value of fiber quality information? !!!!!*

These three questions pose a great deal of concerns among cotton growers, textile manufacturers, and even the developers of testing systems. One of the main reasons for this concern is that fiber quality testing systems essentially produce data, more accurately flood of data; a process that requires a reliable testing system, good calibration, continuous maintenance, spare parts, manpower with some skills, data storage, data retrieval, data handling, and data analysis. These tasks involve high cost and significant time consumption that must be justified and taken into consideration in the profit margin analysis. Indeed, operating a testing laboratory with modern fiber and yarn testing equipment may cost some hundreds of thousands of dollars for small to average size companies and reach millions for larger operations.

In simple terms, the value of quality data can be illustrated by the data-value scale shown in Figure 1. A data of zero value is a data that is unreliable, imprecise, and inaccurate. This is because no matter the intention, any effort to transmit this data into useful information will be a total waste. It is a zero value on the ground that it often reflects operations that are not using reliable testing equipment (no investment in testing) and rely on old systems or subjective evaluation; they are not losing money investing and they are no gaining money utilizing useful data. A negative data value results from data that is reliable, precise, and accurate, but is not transformed into useful and usable information. This is a common dangerous situation particularly in the textile industry, where personnel are too busy producing yarns and fabrics and have neither time nor ability to transmit data into useful and usable information. It is a negative-value situation since the company has to encounter all the costs associated with collecting data mentioned above with no particular benefits. The only time companies following this approach refer to data is when they have serious quality problems or customer complaints. At this time, they are typically unable to see much merits of the data they have since there is no system in place to make them useful or usable in an efficient manner. This, of course, multiplies the losses as a result of missed opportunities.

The positive data value can only result when reliable/precise/accurate data are transformed into useful and usable information that can be quantified into $$ value. This is an aspect that is missing in many textile companies, manly due to the fact that converting reliable/precise/accurate data into useful and usable information is a special task that requires expertise and built-in intelligence in the operation, supported by a great deal of know-how. It also requires a full realization of the value of information. The few companies that have established a system of data-to-info transmission are the ones that are competing in the global market profitably. The best a testing machine developer can do is to design a testing machine that is reliable, soundly calibrated, efficient, and a machine that can generate data that is transformable into useful and usable information. This last feature can never be completed without feedbacks from users and real-time applications.

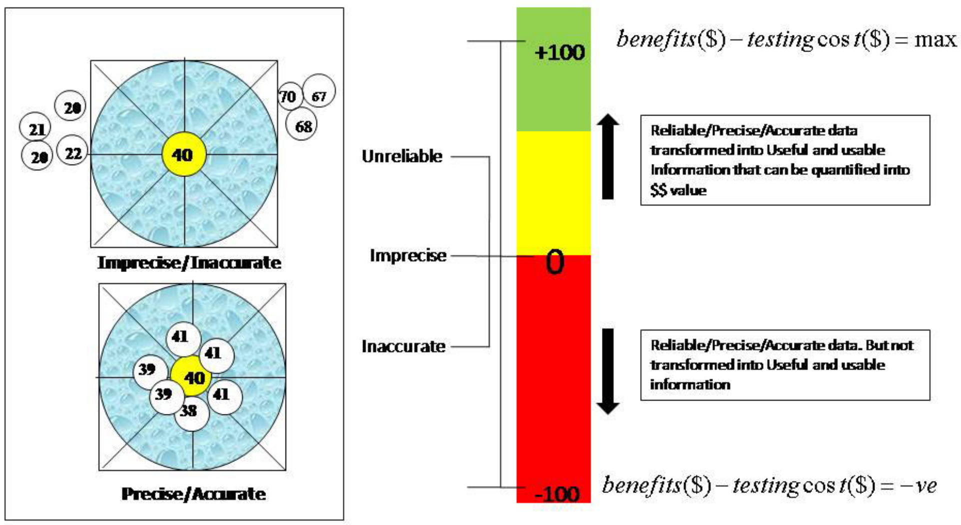

Figure 1. Data-Value Scale

Transforming reliable and accurate data into useful and usable information is the key aspect of this paper. Obviously, there are many ways and approaches to meet this critical task. This paper only focuses on one major aspect to achieve that, which is fiber-to-yarn modeling. This issue is not new; indeed it is one of the oldest issues that the industry has toyed with for many years. Over the years, the concept and the need for fiber-to-yarn modeling has evolved as summarized below.

- 1960s to 1970s- A great deal of focus was on theoretical fiber-to-yarn modeling via stress analysis of yarn and idealized yarn structures [Hearle et al., 1969, Zurek, 1975]
- Early-to-Mid 1980s- Fiber-to-yarn modeling was indeed a hot subject. The emphasis in this period was on empirical modeling using classic multiple regression analysis and neural network. Cotton Incorporated of USA had taken a leadership role in this area with many consecutive conferences and research projects devoted specifically for this subject [El Mogahzy, 1989, El Mogahzy, 1998, Lord, 1988, El Mogahzy and Broughton, 1989, El Mogahzy, 1988]. These efforts were very useful at least from the point of view of realizing the capabilities and the limitations of empirical modeling. However, the limitations outweighed the capabilities as it was commonly realized that no universal empirical model can be developed. A separate model must be developed for each mill, each cotton crop, and each cotton variety.
- 1990s- The subject was put to rest as modeling was perceived to be operation disturbing, time-consuming, and costly. During this period, the principal author of this paper continued his effort to develop fiber-to-yarn models through consultancy work for some textile mills and testing machine developers. This was achieved with full realization of both the capabilities and the limitations of the models developed. Some of the models developed by the principal author included:

- *Models for predicting waste% from certain cotton mixes*
- *Models to predict mechanically-induced neps resulting from the use of certain cotton varieties*
- *Models to predict card wire service life for certain cotton mixes*
- *Models to predict spinning endsdown and loom stops resulting from using certain cotton mixes*

What is new in this Study: The 2000s?

In recent years, a significant renewal of interest in fiber-to-yarn models has been observed as a result of the substantial global changes in the market. A Huge interest by the Chinese industry in fiber-to-yarn modeling was expressed for the purpose of predicting yarn and fabric quality from certain cotton types and for cotton purchasing reasons, mixing strategies, and for performance prediction. In addition, a new practice has been implemented, under the table, in many areas of the world in which high-quality/expensive cottons is mixed with lower-quality/less-expensive cotton under the claim of "all premium cotton". This cotton identity theft was implemented using clever know-how in some developing countries. The impact of such practice is devastating as it can tarnish the true quality of premium cottons, defeat the purpose of making efforts to grow better cottons, and it can have a great adverse impact on the cotton quality and the value balance in the global market. Unfortunately, the data generated by current testing machines can not alone detect this identity theft, as it often appears by the standard data that "All Cottons are Alike".

It was critical therefore to revive the issue of fiber-to-yarn modeling. However, new approaches had to be taken to overcome the difficulties and the limitations experienced in earlier trials using the classical approaches. This is what this study offers, thanks to the generous support of Cotton Incorporated. What is new in the current approach is illustrated by the comparison of the new approach to the classic approaches shown in Table 1.

Table 1.Comparison of the new approach to the classic approaches of Fiber-To-Yarn Modeling

Feature	Classic Approaches	The New Approach
Analysis Tools	***- Least Squares/Regression*** ***- Neural Network***	***- Estimation Approach Using Specially-designed fiber & yarn database*** ***- Judgmental & experience-based analysis*** ***- Some regression analysis and neural networking based on estimation outcomes for the purpose of formatting linear models***
Goal of analysis	***Predicting the actual values of yarn parameters corresponding to certain values of fiber properties in a particular operation***	***Universal models that aim at estimating anticipated values of yarn parameters corresponding to certain levels of fiber properties regardless the operation***
Model database structure	***Data of a wide range of values [3]*** ***Or special laydowns [7]***	***- Extreme and medium levels of fiber attributes*** ***- Extreme and medium levels of yarn attributes*** ***- Full-Factorial Combinations of Fiber & Yarn values*** ***- Directed experimental data to perform judgmental analysis***

In order to implement the estimation approach, data were collected from 16 different companies covering the best, medium & worst quality performance. All common spun yarns were considered: ring-spun, carded & combed, rotor-spun: carded and compact yarns. All common yarn counts were considered (see Table 3). High twist & soft twist yarns were also considered.

Table 3. Yarn counts considered in the Analysis

Ring-Combed	Ring-Carded	Rotor-Carded	Compact-Combed
18	**6**	**4.5**	**18**
20	**8**	**6**	**24**
22	**10**	**8**	**30**
24	**12**	**10**	**40**
26	**15**	**12**	**50**
30	**18**	**15**	**60**
32	**20**	**18**	**70**
36	**22**	**20**	**80**
40	**24**	**24**	
50	**30**	**30**	
60	**36**	**36**	
70	**40**	**40**	
80	**45**		
90			
100			

The new approach taken in this study is based on using a combination of inferential statistical analysis, random-number generation, and limited classic regression analysis to develop fiber-to-yarn models that meet all the statistical criteria, meanwhile satisfy the well-known physical effects of fiber attributes on yarn properties. The uniqueness of this approach primarily stems from the developer ability of making appropriate judgment on the physical nature of fiber and yarn data and the inherent relationships involved.

Inferential statistics was utilized to establish confidence interval on various fiber and yarn properties values following the generalized formula:

a. For nominal-the-best properties (e.g. Micronaire, fiber length, yarn count, and twist):

$$\bar{X} - z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \leq \mu \leq \bar{X} + z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

b. For larger-the-better properties (e.g. fiber strength, color Rd, yarn strength, and yarn elongation):

$$\bar{X} - z_{\alpha}\frac{\sigma}{\sqrt{n}} \leq \mu$$

c. For smaller-the-better properties (e.g. color +b, short fiber content, thin places, thick places, neps, and yarn hairiness):

$$\mu \leq \bar{X} + z_{\alpha}\frac{\sigma}{\sqrt{n}}$$

Random-number generation analysis was utilized for generating random data satisfying specific values of yarn parameters corresponding to certain values of fiber properties. Random numbers are also suitable in situations where data voids are presented. Example of these voids include: the possibility of adding waste fibers to primary cotton, and in situations where different varieties of cotton are blended together.

Classic regression analysis was performed to develop the final models. In this regard, both linear and non-linear models were used. Linear models were in the following general forms:

$$Y = \beta_o + \beta_1 x + \beta_2 x^2 + ... + \beta_k x^k + \varepsilon$$
$$or$$
$$Y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k + \varepsilon$$

where x_i or x_j are the independent variables, β_o, β_1, β_2, ..$\beta_\kappa$are the regression coefficients, and ε is a random error. The polynomial model is considered a linear regression model since the term linear refers to linearity in the parameters (β's) and not the independent variable x. The random error ε is normally distributed with mean of 0 and a variance of σ^2. All classic assumptions associated with regression analysis were taken. These include: existence, independence, linearity, homoscedasticity, and normality.

CATEGORIZATION OF FIBER PROPERTIES

US upland cotton was divided into two major categories, solely on the basis of staple length. These are: short-to-medium staple length category (up to Staple Length of 1.15 inch), and long-staple category (1.15 inch to 1.30 inch). Data of Extra Long Staple cottons were also divided into three categories (1.30 inch-1.40 inch, 1.4 inch-1.5 inch, > 1.5 inch).

Tables 4 and 5 show values of different fiber properties classed by staple fiber length for upland-type cottons. These values largely reflect all practical ranges of fiber properties for these cotton classes.

Table 4. HVI Fiber Properties of Major Staple-Based Cotton Categories

Cotton Category	Quality Level	Len [in]	Mic	Unf %	Str g/tex	Rd	+b	Tr Cnt	Tr Area
Short/Medium Staple	Best	1.15	3.55	86	31.5	81.3	7.5	6.01	0.1
< 1.15	Middle	1.05	4.29	82.27	27.7	75.8	9.4	24.7	0.41
	Worst	0.95	5.12	78.79	23.3	71.2	11	61.4	1.005
Long Staple	Best	1.3	3.39	87.72	37.3	78.6	8.3	7.15	0.095
1.15 to 1.30	Middle	1.2	3.94	84.03	32.3	73.8	10	22.7	0.38
	Worst	1.15	4.59	80.33	27.4	69.1	12	50.7	0.88

Table 5. AFIS Fiber Properties of Major Staple-Based Cotton Categories

Cotton Category	Quality Level	Nep Ct/g	SCN Cnt/g	SFC_w %	SFC_n %	Fin mtx	Mat Ratio	IFC [%]	Dust Cnt/g	Trash Cnt/g	VFM [%]
Short/Medium Staple	Best	132.7	15	5.9	17.8	184	0.95	4.9	216	29.1	0.54
<= 1.15	Middle	299.5	26	9.23	25.8	170	0.9	6.8	619	90.7	1.79
	Worst	498.5	41	12.9	33.3	154	0.85	9.1	1300	186	3.54
Long Staple	Best	93.19	8	4.58	15.6	172	0.955	5	212	24.7	0.515
1.15 to 1.30	Middle	224.9	18	7.03	22.3	160	0.905	6.4	608	76.4	1.635
	Worst	385.9	32	9.93	29.4	148	0.86	8.5	1205	156	3.285

In this part of the study, we were able to detect special patterns of different cotton varieties grown in the U.S. and evaluate predicted values of different cotton crops. These results are shown in Figures 2 through 11. Discussions of these results represent a large part of a Cotton Incorporated report and they can be requested directly from Cotton Incorporated.

Identification of Some Patterns of Particular Cotton Types with respect to Yarn Quality

Examples of Yarn Quality Values obtained from Different Cotton Types

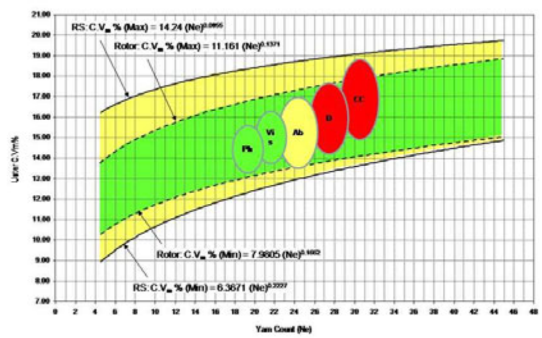

Figure 2 . Cotton patterns w.r.t. Yarn Uster C.Vm% vs. Yarn Count-Ring Spun & Rotor Spun Carded Yarns

Examples of Yarn Quality Values obtained from Different Cotton Types

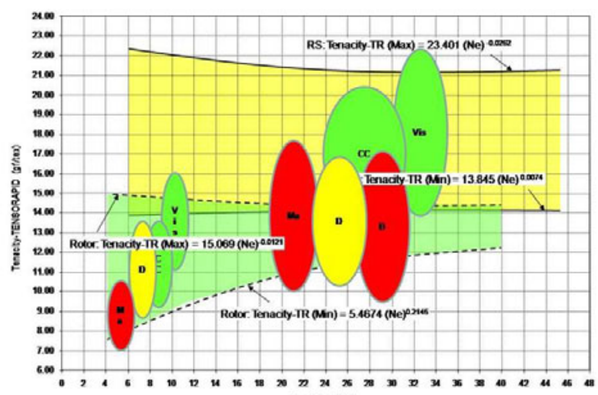

Figure 3 Cotton patterns w.r.t. Yarn Tenacity vs. Yarn Count-Ring Spun & Rotor Spun Carded Yarns

US Crop Evaluation

2007 US Cotton Crop Quality-By Region

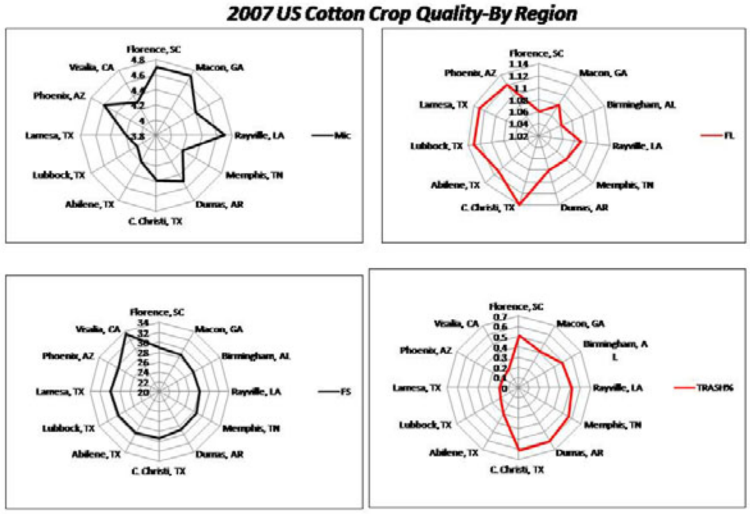

Figure 4

Predicted Yarn Quality -2007 US Cotton Crop Quality-By Region

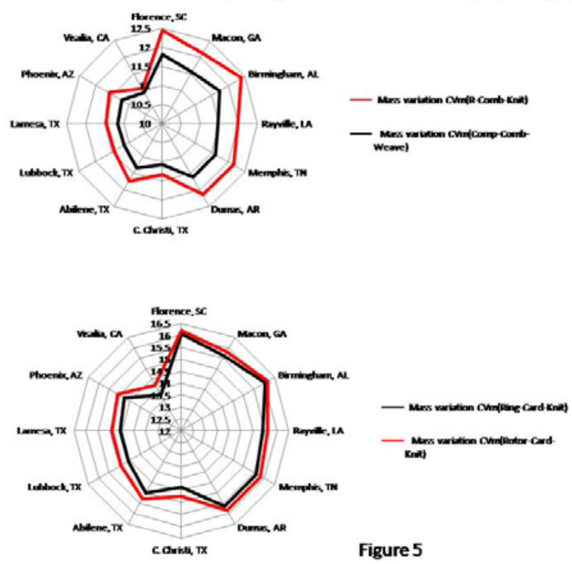

Figure 5

Predicted Yarn Quality -2007 US Cotton Crop Quality-By Region

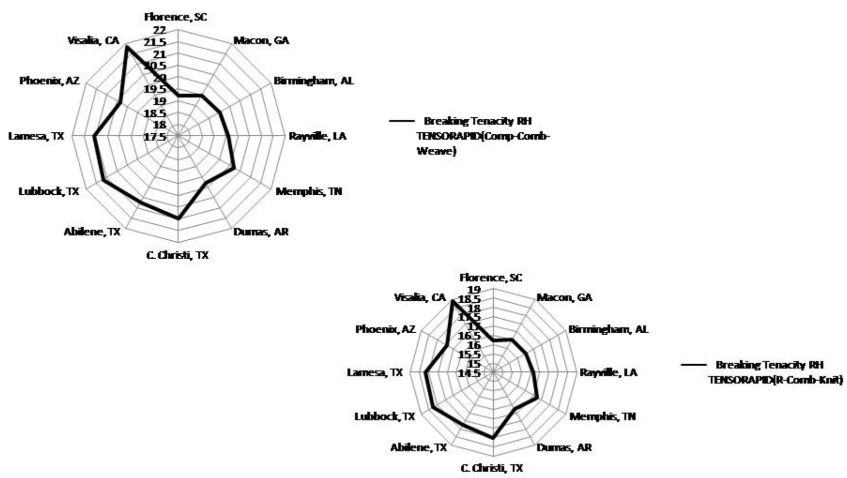

Figure 6

Predicted Yarn Quality -2007 US Cotton Crop Quality-By Region

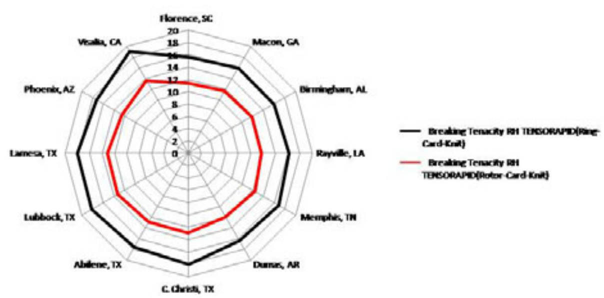

Figure 7

Fiber Quality Profiles of US Cotton Crops

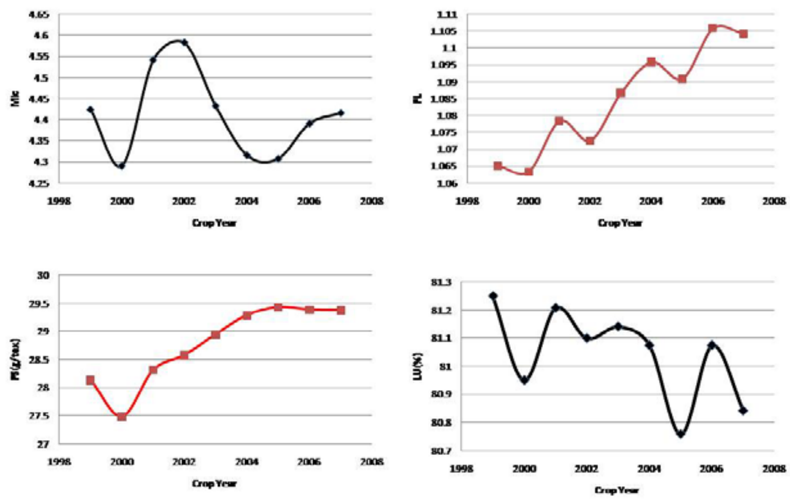

Figure 8

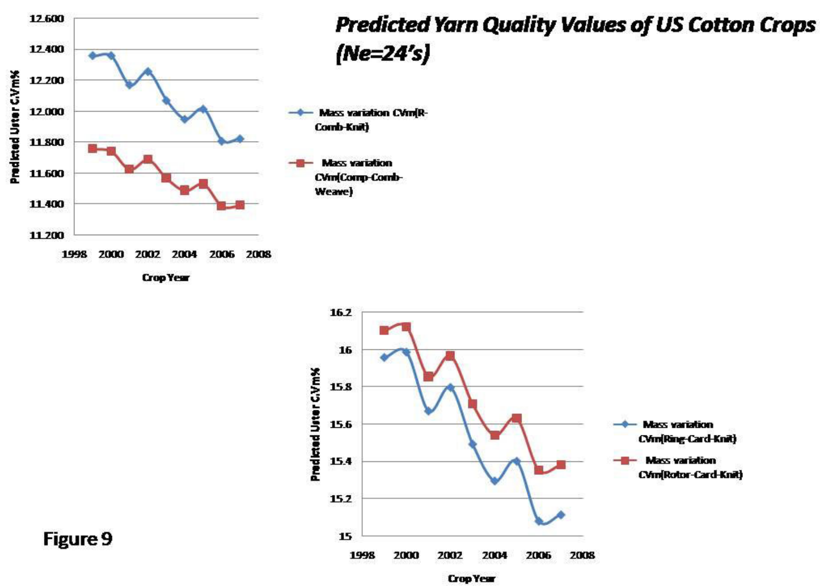

Figure 9

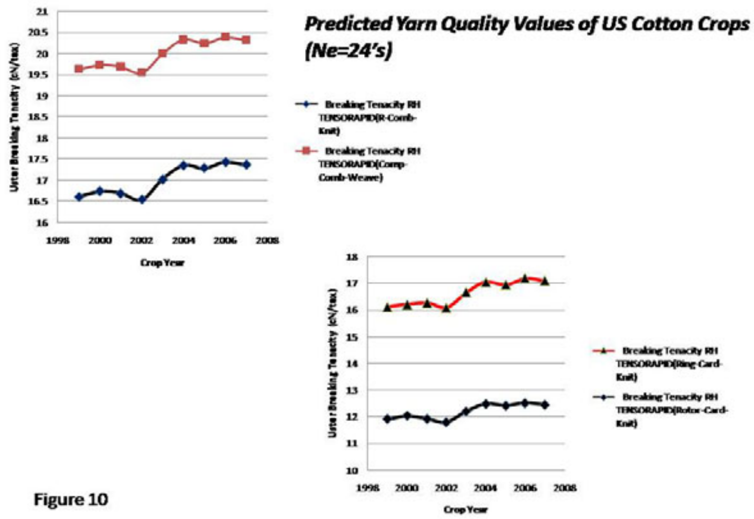

Figure 10

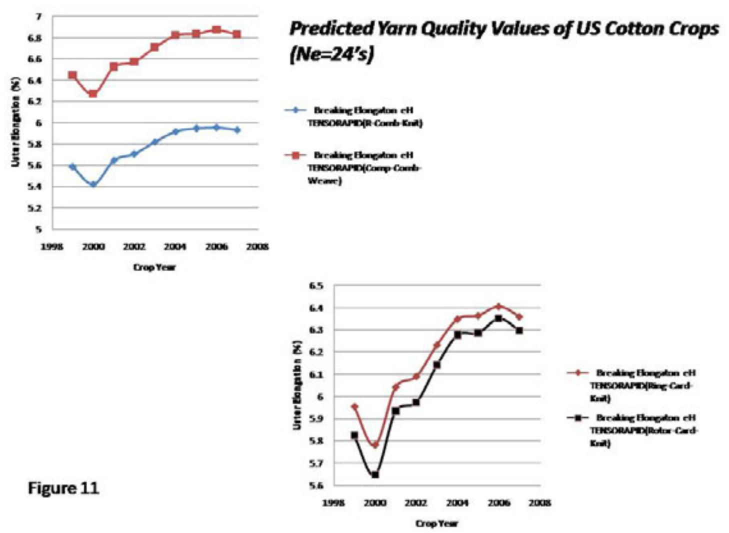

Figure 11

Closing Remarks

We feel extremely good about the performance of the Universal Models-Predictive Powers of >90%. We are currently working on the So-called: "Fiber Recipe Concept"- That is for a given set of yarn properties, what are the optimum combinations of fiber properties w.r.t. quality & cost.

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