PRELIMINARY RESULTS OF COTTONSPEC VALIDATION TRIALS

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<u>Abstract</u>

Cottonspec validation trials have been carried out at three Chinese partner mills. Cottonspec prediction algorithms were upgraded to incorporate yarn structure theory terms and by using an enhanced spinning database. To facilitate wider application of Cottonspec by industry the upgraded algorithms now only require five HVI fiber properties; tenacity, length, elongation, short fiber content and Micronaire. However, there is a room for improved prediction accuracy if other fiber property data become available, e.g. fiber fineness, maturity and nep count. The upgraded algorithms showed greater prediction power than previous versions. Preliminary results reported here showed that for a good modern spinning mill Cottonspec works well with predicted yarn tenacity and evenness closely correlated with measured yarn quality. Prediction accuracy was further improved by introducing Mill Correction Factors (MCFs).

Introduction

Cottonspec is a cotton fiber and yarn quality management software package that predicts yarn properties from measured fiber quality parameters (Yang *et al* 2011). To validate the models used in the software package, validation trials were carried out with three Chinese partner mills. Prior to the trials Cottonspec algorithms were upgraded utilising a large database of industrial spinning quality measurements and employing terms that describe yarn structure theory. The upgraded software was tested using spinning data collected from the three partner mills. A Mill Correction Factor (MCF) was also introduced and tested in these trials. The MCF allows any mill's yarn property results, affected by spinning machine type, settings and quality control regimes to be aligned with the properties of Mill 1, or any other mill or mills whose data is used in generating the algorithms. The results demonstrated that the upgraded Cottonspec algorithms have greater prediction power than the previous version. This paper describes the details of these validation trials.

Methodology

Three Chinese cotton spinning mills were selected for Cottonspec validation trials. Mills 1 and 2 are equipped with modern European spinning systems with the majority of frames utilizing some form of modern yarn compacting in spinning. Both mills produce fine to very fine count yarns in the range from Ne50 to Ne100. Mill 3 is equipped with a mixture of European and Chinese processing machinery.

The validation trials started in December 2010. For Mills 1 and 2 both cotton and yarn samples were tested at the mill. Cotton samples were tested on HVI and other testing equipment, although only HVI values were utilized in these trials. In both Mills yarn samples were tested using an Uster Technologies Uster 3 Yarn Evenness Tester and a Chinese made yarn tensile tester for yarn tenacity and elongation. For Mill 3 cotton samples were collected from the mill and tested at CSIRO using HVI. Yarn samples were tested at the mill on the same type of instruments as Mills 1 and 2.

Results and Discussion

Upgrading Cottonspec Algorithms

Spinning Database

The prediction algorithms used in the early version Cottonspec were developed using a rather small spinning database with a total of 57 lots of yarn data collected from Mill 1. Each lot representing the fiber properties from one bale laydown and the resulting yarn quality. To develop more robust prediction algorithms a large spinning database with a wide range of fine count yarns and various cotton varieties is essential. With strong support from partner mills in this project a larger database of spinning results from industry has been developed. The details of the enhanced database are given in Table I.

Yarn Count Ne	Yarn type		Cotton (in laydowns)
	Compact	Ring spun	
40	/	32	US: CA, SJV
50	210	87	Memphis, Pima
60	388	94	Australia
70	9	/	Xinjiang
80	72	/	Egypt, Israel
Total	679	213	Brazil, India

Table I - Cottonspec spinning database

Prediction Models

A series of spinning prediction models for staple fiber spun yarns developed by Yang and co-workers for a worsted yarn spinning prediction package called Yarnspec (Yang *et al* 1998, 2001, 2002 and 2005) form the basis of Cottonspec. In principal, these models are directly applicable to cotton spinning. With a large spinning database available it becomes possible to apply the physical modelling techniques to develop robust spinning prediction algorithms for fine count cotton yarns.

To illustrate the principle of the work a brief summary of yarn tenacity prediction modelling is described below. Theory and spinning trial results have shown that yarn tenacity is primarily determined by fiber tenacity (Hearle 1969, Yang *et al* 1998). Figure 1 shows an example of the strong correlation observed between yarn tenacity and cotton fiber tenacity for a set of samples from the spinning database.



Figure 1 - Correlation of yarn tenacity with cotton fiber tenacity

To achieve better results of prediction for yarn tenacity a concept of Normalised Yarn Tenacity (NYT) is introduced:

11977 -	Yarn Tenacity
<i></i>	Fibre Tenaoity

Normalised Yarn Tenacity indicates the proportion of fiber tenacity that is realised in the yarn tenacity result. For staple fiber spun yarn NYT is also a function of other fiber properties, e.g. fibre fineness, elongation, length (upper half mean length – UHML) and short fiber content (SFC) etc; NYT is also affected by the level of twist inserted into the yarn.

To determine the effect of twist on yarn tenacity a comprehensive yarn twist curve trial was conducted at Mill 1. Three cotton types were represented in the trial including Acala cotton from the San Joaquim Valley (SJV), US Pima and Brazilian Upland cotton. For each cotton three yarn counts were used; Ne23, Ne32 and Ne40 for the shorter Brazilian cotton, Ne40, Ne50 and Ne 60 for the SJV cotton and Ne50, Ne60 and Ne70 for the US Pima cotton. For each yarn count seven (metric) twist levels were used, ranging from 95 to 132. In total 63 yarns were spun giving nine experimental twist curves to show (model) the dependence of yarn tenacity on twist level.

Due to the limited number of twist levels used in the trial not all curves showed a tenacity maxima. Indeed, the shape of the twist curve was largely dependent on cotton growth reflecting fiber length differences and yarn

count. For simplicity, an average of the Ne50 and Ne60 yarn twist curves were used to develop a theoretical yarn twist model. Experimental data fitted to this theoretical twist curve showed good agreement.

The averaged theoretical yarn twist model is shown in Figure 2. It shows that yarn tenacity increases with increasing yarn twist level and reaches a maxima at a twist factor of around 120. Note the yarn tenacity in vertical axis of this Figure is the measured yarn tenacity normalised to the average yarn tenacity at each twist level. This normalised yarn tenacity for each twist level is called the yarn tenacity twist correction factor (TCF).



Figure 2 – Cotton spinning yarn twist model

To exclude the effect of yarn twist on yarn tenacity the concept of Twist Corrected Normalised Yarn Tenacity (TCNYT) is introduced and defined as:



Theoretically, TCNYT is independent of fibre tenacity and yarn twist. However, experimental results show that fiber tenacity has a secondary effect on observed yarn tenacity. This is a result of the fiber length changing as a result of fiber breakage during processing. Fiber breakage depends on the fiber work-to-break value, which in turn is the product of fiber tenacity and elongation.

Utilising the now larger spinning database, a spinning prediction model for TCNYT was developed, containing the independent variables of predicted yarn evenness, Micronaire, SFC, length and tenacity; the fiber properties selected on the basis of a competative stepwise regression. The predicted yarn evenness model was developed based on theoretical yarn evenness prediction model (Yang *et al* 1998) and fitted with the data from the large size spinning database. As a result, predicted yarn tenacity can be expressed by the following equation:

PYT = TCNYT(predicted CV%, Mic, SFC, UHML, FT) x FT x TCF

To facilitate wide application of Cottonspec by industry the upgraded Cottonspec prediction algorithms now require only five HVI test results: tenacity, elongation, length, SFC and Micronaire; although there is a room for improved prediction accuracy if faster, widespread tests for other fiber property values become more widely available, e.g. fiber fineness, maturity and nep count.

Mill Correction Factors

The quality of a spun yarn is predominantly affected by the quality of the cotton used to spin the yarn. However, other factors, e.g. the quality of textile machinery, maintenance schedules, settings and quality control regimes play a role in determining the measured yarn quality.

To make Cottonspec a useful quality control tool for a range of spinning mills it is necessary to introduce Mill Correction Factors (MCFs). For example, predicted yarn tenacity for Ne60 yarn is expressed as:

FYT = TCNYT(predicted CV%, Mic.SFC, URML, FT) x FT x TCF x MCF(YT Ne60)

For standard Cottonspec the default value for all MCFs is one. For a particular mill MCFs may be adjusted after a certain period of time when enough processing data is accumulated. For a particular yarn property of a given yarn count, the MCF is one minus the average variations between predicted and measured yarn property:

$$MCF = 1 - \frac{\Sigma(Predtoted - Measured)/Measured}{n}$$

where, n = the number of yarn lots. In majority cases MCF is expected to be yarn count dependent.

With the prediction models as described, algorithms were derived using the spinning database mentioned earlier. Applying these prediction algorithms calculated yarn evenness and tenacity values vs. measured values for a set of 362 Ne50-80 compact spun yarns are shown in Figure 3. It is seen that calculated yarn evenness and tenacity are highly correlated to measured values with the square of the correlation coefficients (R^2) being 0.84 for yarn evenness and 0.94 for yarn tenacity.



Figure 3 – Calculated vs. measured (left) yarn evenness, (right) yarn tenacity from 362 Ne50-80 yarns produced in Mill 1

Validation of Cottonspec algorithms

Mill 1

Predicted yarn evenness and tenacity values from applying standard Cottonspec algorithms, i.e. with MCFs = 1, to a validation set of 123 lots of Ne50-80 yarn data collected from Mill 1 are shown plotted against measured values in Figure 4. Error of prediction values are listed in Table II.



Figure 4 – Predicted vs. measured (left) yarn evenness and (right) yarn tenacity values for 123 Ne50-80 validation yarn results for Mill 1

 Table II – Errors for predicted values for the 123 Ne50-80 yarns for Mill 1

Standard Errors Relative Standard Errors %		l Errors %		
Evenness %	Tenacity cN/tex	Evenness%	Tenacity%	
0.42	0.84	3.28	3.73	

It is seen that measured yarn evenness and tenacity are highly correlated to the predicted values with the R^2 being 0.81 for yarn evenness and 0.85 for yarn tenacity and the prediction errors being relatively small. These results demonstrate that the prediction algorithms work well for Mill 1.

Mill 2

Applying standard Cottonspec (MCFs=1) to 83 lots Ne50-80 yarn data collected from Mill 2 predicted yarn evenness and tenacity against the measured are shown in Figure 5. Prediction errors are given in Table III.



Figure 5 – Predicted vs. measured (left) yarn evenness and (right) yarn tenacity values for 83 Ne50-80 validation yarn results for Mill 2.

MCF	Standard Errors		Relative Standar	rd Errors %	
	Evenness %	Tenacity cN/tex	Evenness%	Tenacity%	
no	0.68	0.85	5.01	4.80	
yes	0.46	0.61	3.43	3.41	

Table III - Errors for predicted values for the 83 Ne50-80 yarns for Mill 2

It is seen that the prediction accuracy for Mill 2 is reasonably good with R^2 values of 0.83 for yarn evenness and 0.75 for yarn tenacity. The prediction errors are similar to that for Mill 1 for yarn tenacity and slightly greater than for Mill 1 for yarn evenness. This indicates Cottonspec yarn evenness and tenacity prediction models work reasonably well for modern mills like Mill 1 and Mill 2.

To further improve the prediction accuracy MCFs for yarn evenness and tenacity for various Mill 2 yarn counts have been worked out and are detailed in Table IV.

Yarn count Ne	Yarn Evenness	Yarn Tenacity	
80	1.053	1.047	
70	1.050	0.990	
60	1.021	1.010	
50	0.980	1.043	

Table IV – MCFs for yarn evenness and tenacity for Mill 2

It is seen the MCFs for both yarn evenness and tenacity are close to one for all yarn counts. This illustrates that the prediction models work reasonably well across a range of yarn counts and varieties of cottons of different qualities. Using MCFs shown in Table IV predicted yarn evenness and tenacity versus the measured for 83 lots Ne50-80 yarns are shown in Figures 6.



Figure 6 – Predicted vs. measured (left) yarn evenness and (right) yarn tenacity values for 83 Ne50-80 validation yarn results for Mill 2.

The prediction errors for yarn evenness and tenacity are shown in Table V. The results show the prediction accuracy is significantly improved with MCFs. This demonstrates that Cottonspec works reasonably well for a good modern mill without MCFs and introducing MCFs can greatly enhance the prediction power of Cottonspec.

Mill 3

Applying standard Cottonspec (MCFs=1) to 46 lots of Ne50-70 yarn data from Mill 3 the predicted yarn evenness and tenacity against the measured are shown in Figure 7. Prediction errors are given in Table V.



Figure 7 – Predicted vs. measured (left) yarn evenness and (right) yarn tenacity values for 46 Ne50-70 validation yarn results for Mill 3.

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MCF	Standard Errors		Relative Standar	d Errors %	
	Evenness %	Tenacity cN/tex	Evenness%	Tenacity%	
no	0.63	0.70	5.12	3.84	
yes	0.30	0.49	2.40	2.47	

 Table V – Prediction errors for 46 Ne50-70 varns for Mill 3

These validation trials show the situation for Mill 3 is rather different from Mills 1 and 2. On average, the measured yarn evenness was significantly higher than predicted while the measured yarn tenacity was lower than predicted. The correlations between the predicted and the measured yarn quality are significantly lower than for Mills 1 and 2. This indicates that the quality control status at Mill 3 is not as good as Mills 1 and 2. In this context Cottonspec works like a ruler that can tell a mill's quality control status. If measured yarn quality is close to predicted values the conclusion can be drawn that the mill is a good mill. For a mill with poor quality control status the main purpose of Cottonspec is to benchmark the mill's performance against the best commercial practice rather than trying to achieve accurate predictions. Actually, the large scatters observed for Mill 3 are mainly caused by poor quality control procedures, e.g. improper sampling, non-standard testing conditions, human errors and poor machine maintenance etc. As the quality control status improves the scatters will reduce and good prediction accuracy will be achieved.

To improve the prediction accuracy mill correction factors for yarn evenness and tenacity for various yarn counts have been worked out as detailed in Table VI. Using the MCFs the predicted yarn tenacity and evenness versus the measured for 46 lots Ne50-70 yarns are shown in Figure 8.

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Yarn count Ne	Yarn Evenness	Yarn Tenacity	
70	1.001	0.977	
60	1.017	1.012	
50	1.046	0.981	

 Table V – MCFs for yarn evenness and tenacity for Mill 3



Figure 8 – Predicted vs. measured (left) yarn evenness and (right) yarn tenacity values for 46 Ne50-70 validation yarn results for Mill 3.

It is seen that the prediction accuracies are greatly improved with MCFs although a large scatter was still obvious. It has to be emphasised that it is of critical importance to improve the mill's quality control procedures before expecting good prediction accuracies with Cottonspec.

For the purpose of comparison the correlation coefficient between the measured and the predicted yarn evenness and tenacity values as well as the prediction errors for the three mills are summarized in Table 7.

	1.65	R² Standard Error		l Errors	ors Relative Errors %			
VIII	MCF	CV% YT cN/tex		CV%	CV% YT cN/tex		CV% YT cN/tex	
1	no	0.81	0.85	0.42	0.84	3.28	3.73	
2	no	0.83	0.75	0.68	0.85	5.01	4.80	
	yes	0.87	0.76	0.46	0.61	3.43	3.41	
3	no	0.43	0.47	0.63	0.70	5.12	3.84	
	yes	0.48	0.59	0.30	0.49	2.40	2.47	

Table VI $- R^2$ and prediction errors with and without MCFs for partner mills

Conclusion

Cottonspec validation trials have been carried out at three Chinese mills. A comprehensive industrial spinning database was developed with strong support from these partner mills. Cottonspec algorithms were upgraded with the newly developed spinning database and by employing sophisticated mathematical modelling.

To facilitate wide applications of Cottonspec by the industry the upgraded Cottonspec algorithms require only five HVI testing data: fiber tenacity, elongation, length, SFC and Micronaire. To further improve prediction accuracy some other fibre properties may be included in the future, e.g. fiber fineness, maturity and nep count.

The results showed that for a good modern spinning mill Cottonspec works well with predicted yarn evenness and tenacity closely correlated to measured yarn quality. Prediction accuracy is further improved by introducing MCFs. For a mill with poor quality control status low correlations between the predicted and the measured yarn quality is observed and with large scatters. With MCFs the prediction accuracy improves to some extent. As the quality control status improves the scatter associated with some mills will reduce and good predictions will be achieved. Cottonspec applications for these types of mill should be focused on benchmarking the mill's performance against the best commercial practice rather than prediction accuracy.

Acknowledgements

The authors wish to acknowledge the three Chinese partner mills for participating in the Cottonspec validation trials. The work was supported by the Australian Government through the Department of Agriculture, Fisheries and Forestry (DAFF), Cotton Catchment Communities Cotton Research Council (CCC CRC), Cotton Research and Development Corporation (CRDC), and CSIRO.

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