Optimisation of Cotton Fibre Blends using AI Machine Learning Techniques

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Abstract: Fibre blend should be composed regarding the requirements and allowable price of the textile end product. Using the appropriate raw material and optimised fibre blends we can influence the mechanical properties and regularity of a yarn as well as significantly reduce the number of yarn faults.
The contribution presents a study of the influence of quality characteristics of cotton fibres and constructional parameters of a yarn on the most important properties of cotton yarn. The achieved results have been used for determination of optimised cotton fibre blends regarding the quality and price of a cotton yarn. A complex procedure of cotton fibre blend determination significantly depends on suitable models for prediction of properties of resulting cotton yarns, in-depth knowledge of characteristics of cotton fibres and consideration of parameters of a production process. The results of a theoretical part of the research have been summed up in a model of cotton yarn engineering, which main components are regression model for prediction of properties of cotton ring and rotor yarns, and model for optimisation of cotton fibre blends regarding the quality and price. The regression prediction model has been designed using one of the popular artificial intelligence methods: the machine learning from examples. The prediction accuracy for forecasting the breaking tenacity, breaking extension, and regularity of cotton yarns, as well as amount of yarn faults, was significantly improved. The obtained regression trees served as a basis for realisation of a model for optimisation of cotton fibre blends regarding the quality and price of resulted yarn. Special linear programming techniques, supplemented by specific spinning technology constraints have been used for this purpose.
In order to enable the comparison between the predicted and measured properties of investigated properties of cotton yarns, a new method of analytical evaluation and graphical representation of a so-called Yarn "Total Quality Index – TQI" was developed. The graphical representation has a form of a control diagram and because of its clearness provides a potential for a referential document of a modern spinning mill. Furthermore, it can be successfully used for establishing the indubitable dialogue between a spinning mill and its customers. TQI was developed based on referential information of textile fibres and yarns, included into Uster Statistics.

Key-Words: cotton fibre, cotton yarn, fibre blends, artificial intelligence, machine learning

1 Introduction

Modern concepts of computer based information systems to support the yarn engineering/ optimisation of fibre blends, as well as for collection and processing of data, relevant for the whole spinning process, have to be used today in order to assure a reliable production process and high/constant quality of semi- and final products.

With the aim to build the computer programme to support the quality/price optimisation of fibre blends, a model for yarn engineering using machine learning from examples and appropriate optimisation methods were first studied and developed. Induction of regression trees to predict the most important cotton yarn properties coming out from cotton fibre and fibre blend properties made possible to effectively determine the yarn characteristics before entering the actual production. The constructed regression trees and certain constraints served as a base for optimisation of quality and material costs of cotton mixture composition. Machine learning from examples and optimisation programs were successfully integrated into the computer programme for optimisation of cotton yarn blends.

Collection of relevant spinning data and application of results of optimisation methods were carried out in a real production environment – spinning plant that produced carded and combed cotton-type spun yarns.

2 Engineered Fibre Selection

Yarn engineering as a process of yarn quality planning and manufacturing of yarn based on the fibre properties is becoming more and more important in today's textile climate and competitive environment. The theory on how fibre materials react during spinning process is still insufficient. This is the reason that the cotton spinning mills buy too good and therefore too expensive cottons. Only with detailed knowledge of the raw material to be processed and its reaction during the process we are in position to achieve an optimum setting of production machines and to fully exploit the quality potential of the raw material. The accurate tools to predict quality properties of yarn taking into consideration the raw material physical and mechanical characteristics as well as to optimise the fibre mixture are needed to assure the effective use of cotton fibres [1,2]. Raw material can best be utilised if a computer-based yarn engineering and bale selection/ management systems are available. Machine learning techniques could be effectively used to predict the yarn properties coming out from characteristics of the raw material. The accurate prediction of the quality of yarn is a first step to the determination of an optimal fibre mix and therefore the minimisation of the raw material costs, appropriate and constant quality of the yarn and greater share of profit, optimised weaving process and higher quality of produced fabrics.

In the spinning mill we use the combination of on-line and off-line quality assurance and data collection/processing systems which ensure that the process faults are detected at an early stage, so that the amount of downgrade material can be reduced.

Yarn engineering is referred to the fine tuning of the fibre properties in the bale mix to the requirements of the end product. With such optimisation we can achieve improved yarn quality, higher production, and reduction of yarn costs. Effective fibre testing systems, together with application of modern computer hardware and software, enabled new approaches to yarn engineering and cotton fibre selection.

The experience, obtained by development and use of machine learning techniques, as well as the existing CAPP (Computer aided process planning) software, enabled the design of an integrated computer programme for use in a cotton-type spinning mill. The programme consists of [3,4]:

- module for input of data,
- data base,
- module for prediction of properties of yarn,
- module for determination of cotton fibre mixtures, and
- CAPP module.

RETIS machine learning system [5] is used as a prediction module and linear inequalities' system solver is used to support the fibre blend determination module.

3 Data Sets and Optimisation of Fibre Blends

The system for automatic induction of regression trees RETIS was used for the construction of several regression trees with different pruning degrees. Regression trees are similar to classification trees, with the difference that while classification trees are used to classify objects into discrete classes, regression trees are used when the class is continuous. The attributes - fibre quality characteristics – were used to predict the most important yarn properties for the weaving process. By learning regression trees these properties of cotton yarn were determined as a function of fibre properties.

We can present the constructed regression trees in a textual or in graphical form. The graphical representation is preferred because of its logical and simple interpretation. To determine one of the properties of a new cotton mix, we simply follow the values of attributes in the appropriate tree and read the value in a leaf. A part of a learning example set - cotton fibre and yarn characteristics - is presented in Table 1.

The basic partition of regression trees into subtrees, was made taking into account the main technological and constructional parameters: type of technological process of spinning, linear density of a yarn, and yarn twist. Properties of cotton fibres, used as components of cotton mixtures, were included into a separate file. A particular file was created also for properties of cotton mixtures, from which the yarns, included in learning examples, were produced. A part of mixture composition for yarns, included in learning examples, is given in Table 2.

Table 1: The learning examples set

No.	TP	TEXM	TWIST	CROSS	Y-STR	F-STR	MAT	FIN	M-L	C-L	%U10	W%U10	%AML	T-C	S-C
1	1	30.78	720.00	160.00	13.30	42.24	81.39	4.91	16.71	29.90	33.58	11.00	47.98	3.38	0.25
2	1	29.70	670.00	160.00	15.05	42.24	83.87	4.90	14.46	28.59	44.65	16.00	45.91	5.23	0.25
3	1	29.50	697.00	160.00	13.59	43.38	80.00	4.83	16.22	29.30	36.45	12.25	45.59	5.80	0.13
…															
326	3	29.80	837.00	194.00	11.70	42.46	81.24	3.99	14.64	32.19	29.46	9.83	53.33	3.56	0.00

Table 2: Cotton mixture composition

LE Cons.No.	% FT1	% FT2	% FT3	% FT4	% FT5	% FT6	% FT7	% FT8	% FT9	% FT10	SUM
1-10	12.00	38.00	29.00	14.00						7	100
11-33	13.00	41.00		25.00		15.00				6	100
34-48	28.00	19.00	31.00	14.00	4.00	3.00				1	100
…											
313-326								50.00	45.00	5	100

Remark: LE Cons.No means: Learning Example Consecutive Number from Table 1.

Constructed regression trees were used for prediction of the most important cotton yarn properties: breaking tenacity, breaking extension, irregularity, number of thin/thick places and neps. To determine one of the mentioned properties of a new cotton mix, we simply follow the values of fibre attributes in the appropriate tree and read the value in a leaf.

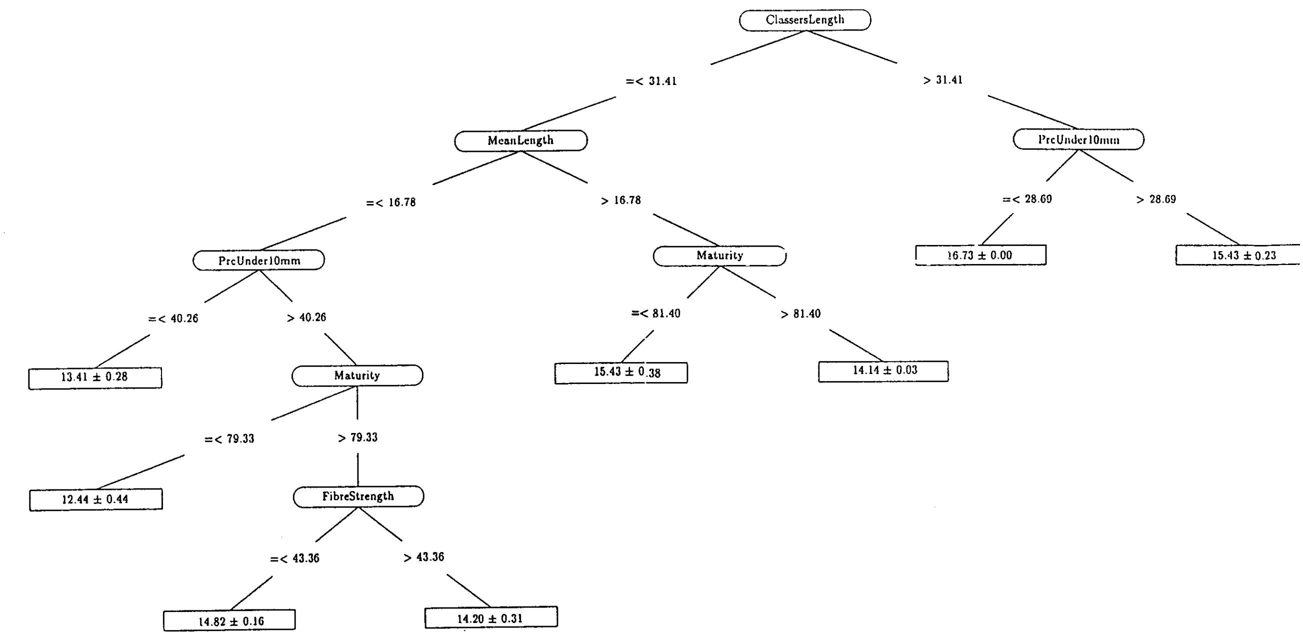

Figure 1: Regression tree for prediction of yarn tenacity

Designed regression trees can be used to evaluate the class value for new examples. The attribute values can be inputted into the system which interprets the tree automatically and calculates the class value of the new example. One of the regression tree that served for the prediction of yarn tenacity (in cN/tex) is shown in Figure 1. Once the regression trees are built, it is possible to start the optimisation process using linear programming algorithms with particular constraints. The optimisation must take into account both quality of a yarn to be produced and material costs. The optimisation process can be described in a form of the following steps:

- Appropriate regression tree must be chosen.
- We decide, which leaf in a regression tree is the most important for a certain yarn property.
- Path, describing the way to this leaf determines a system of linear inequalities.
- Additional constraints can be given.
- Using the linear inequalities' system solver we search the objective function.

4 Results and Discussion

High degree of correlation between the predicted and measured values of yarn properties was established when testing the accuracy of prediction module of the programme. The correlation coefficients [4] varied between 0.85 (number of thick places) and 0.98 (yarn breaking tenacity). The tree, shown in Figure 1, was induced using the prediction module of the programme. It has seven nodes and eight leaves. The optimisation module of the programme produced linear programs for each of the regression tree leaves. It considered the number of variables and constraints to set up the objective function. The minimal value of the objective function, i.e., fibre blend price, was calculated as a solution. At the end of the procedure, the share of each fibre blend component was given in a form of optimal variable values. One of the optimisation results is shown in Figure 2.

```
PROBLEM: YAST1_IN/Leaf #5

  Number of variables = 10
  Number of constraints = 14
-------------------------------------------------------------------------------
CONSTRAINTS:
  C01:  + 30.33 x1 + 29.60 x2 + 28.60 x3 + 26.94 x4 + 28.70 x5 + 28.13 x6 + 28.73 x7 + 31.90 x8 + 31.63 x9 + 21.02 x10 <= 31.41
  C02:  + 16.55 x1 + 15.23 x2 + 14.83 x3 + 13.27 x4 + 13.58 x5 + 14.20 x6 + 13.84 x7 + 19.23 x8 + 16.86 x9 + 10.44 x10 >= 16.78
  C03:  + 82.87 x1 + 85.50 x2 + 81.57 x3 + 82.71 x4 + 80.00 x5 + 79.49 x6 + 78.02 x7 + 82.37 x8 + 80.35 x9 + 72.47 x10 <= 81.40
  C04:  +  1.00 x1 +  1.00 x2 +  1.00 x3 +  1.00 x4 +  1.00 x5 +  1.00 x6 +  1.00 x7 +  1.00 x8 +  1.00 x9 +  1.00 x10  =   1.00
  C05:  +  1.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C06:  +  0.00 x1 +  1.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C07:  +  0.00 x1 +  0.00 x2 +  1.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C08:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  1.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C09:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  1.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C10:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  1.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C11:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  1.00 x7 +  0.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C12:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  1.00 x8 +  0.00 x9 +  0.00 x10 <=  1.00
  C13:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  1.00 x9 +  0.00 x10 <=  1.00
  C14:  +  0.00 x1 +  0.00 x2 +  0.00 x3 +  0.00 x4 +  0.00 x5 +  0.00 x6 +  0.00 x7 +  0.00 x8 +  0.00 x9 +  1.00 x10 <=  1.00
OBJECTIVE FUNCTION:
  y =  + 324.00 x1 + 310.00 x2 + 297.00 x3 + 290.00 x4 + 270.00 x5 + 257.00 x6 + 296.00 x7 + 315.00 x8 + 298.00 x9 + 130.00 x10
-------------------------------------------------------------------------------
SOLUTION:
  Minimal value of objective function:
    y = 263.44
  Optimal variable values:
    x01 =  0.00
    x02 =  0.00
    x03 =  0.00
    x04 =  0.00
    x05 =  0.00
    x06 =  0.00
    x07 =  0.00
    x08 =  0.72
    x09 =  0.00
    x10 =  0.28
-------------------------------------------------------------------------------
```

Figure 2: Optimisation results for leaf No. 5

Explanation of terms:

- Number of variables: number of cotton fibres - components of fibre mixtures.
- Number of constraints - number of all constraints taken into account.
- Objective function - the price of the cotton fibre mixture which is to be minimised.
- Solution:
  - Minimal value of objective function - minimised value of the mixture price that can be achieved considering the given constraints.
  - Optimal variable values: share of mixture components.

Each leaf of the tree was analysed automatically by the programme in order to achieve best possible results of optimisation regarding the give preconditions. In above given example, the solution which followed from the leaf No. 5 can be treated as optimal one taking into account both cotton yarn strength and fibre blend price. The solution, given by the programme module for cotton blend optimisation, is as follows:

"The optimised cotton fibre blend, which will (considering the actual production stages and production lines/machines, used the regression prediction model) enable the production of a yarn with breaking tenacity of 15.43 cN/tex, is composed of 72 % of fibre type No. 8 and 28 % of fibre type No. 10."

In close co-operation with our industrial partner, we have applied both described modules of the programme to optimise the cotton fibre blend for spinning using the carded cotton line. We fed the system with information regarding the available raw materials. After finished optimisation process the cheapest cotton fibre mixture was determined that should enable the production of yarns with properties, required in technical documentation. Price of the fibre blend, proposed by the programme was lower for nearly 2 % when compared with the previous one used for production of the same yarn.

5 TQI - Yarn Total Quality Index

In order to assure the comparison between the predicted and measured properties of cotton yarns, an entirely new method for analytical evaluation and graphical representation of a so-called "Total Quality Index – TQI" [6] was created.

TQI is based on application of Uster Statistics [7] and is defined in a following way:

$$TQI = f\,(\text{Yarn Properties(U)}\ ^{*})\,; \qquad 0 < TQI \le 1$$

We dealt with the 6 yarn properties, therefore the expression gets this form:

$$TQI = \big(Y\text{tenacity(U)}^{*} + Y\text{elongation(U)} + Y\text{irregularity(U)} + Y\text{Thick pl.(U)} + Y\text{Thin pl.(U)} + Y\text{no. of neps(U)}\big)/6$$

The higher TQI, the higher is estimated yarn quality. Above all the graphical representation of TQI enables a clear and quick insight into yarn quality regarding the most important yarn properties and can therefore also be used as a control/referential document of a modern spinning mill. Figure 3 presents TQI for OE-rotor yarn having linear density of 40 tex.

* Remark: Yarn property(U) means a relative value regarding the Uster Statistics [7].

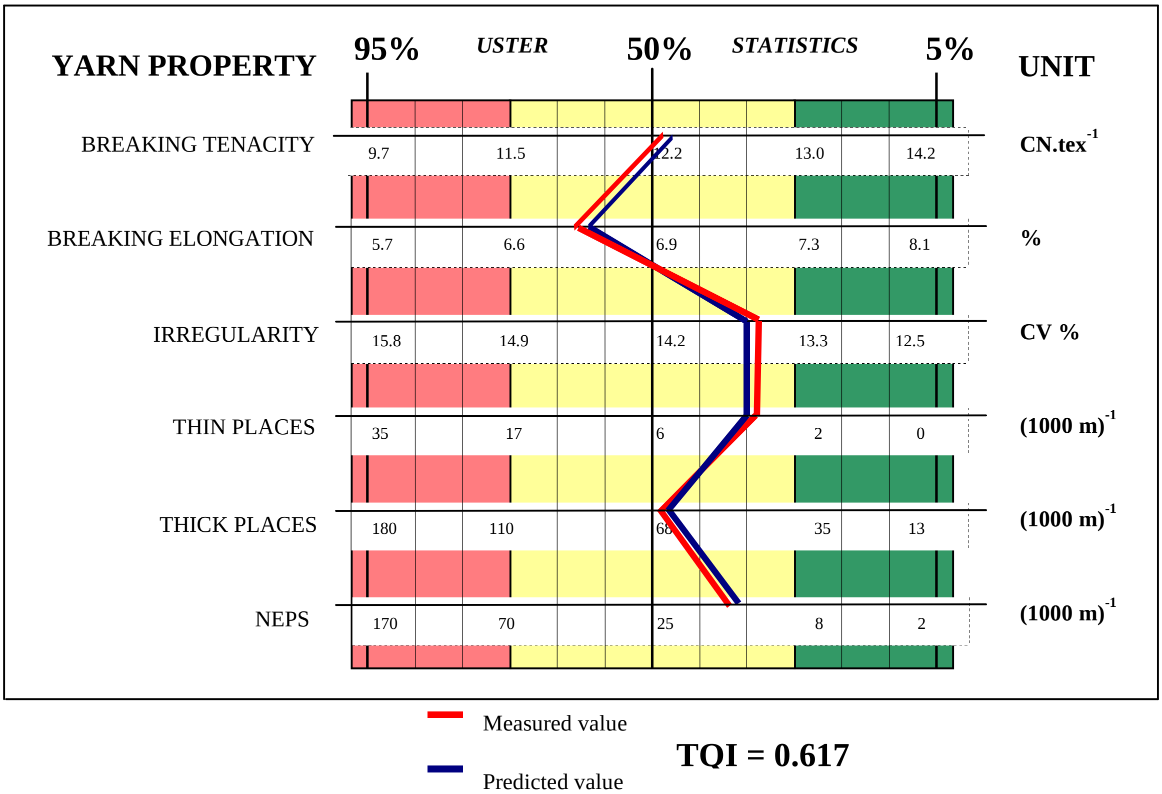

Figure 3: TQI of OE-rotor yarn, 40 tex

6 Conclusions

A complex procedure of cotton fibre blend determination significantly depends on suitable models for prediction of properties of resulting cotton yarns, in-depth knowledge of characteristics of cotton fibres and consideration of parameters of a production process. The results of a theoretical part of the research have been summed up in a model of cotton yarn engineering, which main components are regression model for prediction of properties of cotton ring and rotor yarns, and model for optimisation of cotton fibre blends regarding the quality and price. The regression prediction model has been designed using one of artificial intelligence methods: the machine learning from examples. The prediction accuracy for forecasting the breaking tenacity, breaking extension, and regularity of cotton yarns, as well as amount of yarn faults, was significantly improved. The obtained regression trees served as a basis for realisation of a model for optimisation of cotton fibre blends regarding the quality and price of resulted yarn. Special linear programming techniques, supplemented by specific spinning technology constraints have been used for this purpose.

A new method of analytical evaluation and graphical representation of a so-called Yarn "Total Quality Index – TQI" was introduced that enables the comparison between the predicted and measured properties of investigated properties of cotton yarns. The graphical representation has a form of a control diagram and because of its clearness provides a potential for a referential document of a modern spinning mill. Furthermore, it can be successfully used for establishing the indubitable dialogue between a spinning mill and its customers.

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