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OPTIMIZATION OF YARN QUALITY AND COST WITH DIFFERENT COMBINATIONS OF FIBER VARIETIES USED IN COTTON SPINNING MILLS

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ABSTRACT

This paper deals with the study of optimum mixing of different cotton varieties with varying properties. Suitable multi-objective mathematical model has been formulated so as to minimize the overall cost and maximize the desired quality of the output, the yarn. Applying the norms recommended by South India Textile Research Association (SITRA), various groupings of fiber varieties were proposed. By using Goal programming approach, optimal proportions of fiber varieties were identified for maximum quality and minimum cost. These results are expected to assist the spinning mill managers in their decision-making on raw materials inventory.

Keywords*:* Spinning process, Cotton properties, Multi-objective optimization, Goal programming.

1. INTRODUCTION

Mixing of various varieties of cotton has been a major manufacturing practice since the beginning of cotton textile industry. A cotton fiber is a peculiar object. It has no fixed length, width, thickness, and shape and cross-section. Moreover the properties like fiber length, fineness, strength, maturity, rigidity and other structural features may vary. This may be due to the variations in growth factors like dietary, metabolic, nutrient supply, topography, seasonal and weather. Spinning system is an important system in textile industries, which consists of a set of processes to convert raw cotton into yarn. In spinning system the raw cotton is ginned (impurities removed) and pressed in bales of 170 kg each for supply to mills where it will be converted into yarn.

The main technical challenges in the spinning mills are to convert the high variability in the characteristics of cotton to a uniform end product, yarn. This critical task is mainly achieved in the mixing (blending) process. Mixing of different cotton varieties with varying properties and cost in an optimal proportion would reduce overall yarn production cost. In this process the optimal proportion should not impair quality and processing efficiency. In this paper an attempt has been made to study and propose the optimum mixing of cotton varieties and cost for desired level of the out put, yarn quality.

1. 1 QUALITY LEVELS OF COTTON FIBERS

Cotton producing areas are spread throughout in India. There are nine major cotton producing states producing thirty varieties of cotton with different properties [1]. Among the various fiber properties of cotton, fiber length (FL), fiber fineness (Micronaire - MC) and fiber strength (FS) are highly influencing on the yarn quality (CSP-Count Skein Product). Properties of cotton varieties with prevailing cost are presented in Table 2.

The South Indian Textile Research Association (SITRA) has recommended the groupings of cotton varieties for the production of different yarn quality (expressed in counts), which are presented in Table 2.

1.2. ROLE OF OPTIMIZATION IN COTTON MIXING

One of the common approaches in mixing is massive blending, in which vast quantities of bales (cleaned and pressed cotton in packs) are mixed by grade or growth area, to reduce variability, which is not fully a scientific approach. Optimization techniques such as mathematical linear programming can be used to calculate the composition of the mix, that allows yarn to be spun in the properties that were put forward at the cheapest price [2]. El Mogahzy and Gowayed [3-5] have studied and applied extensively the simplex method for optimizing independently the cotton costs

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and the fiber quality. According to them the best mixing can be done with minimum cost Linear Programming approach.

Minimizing the cost and maximizing the quality of yarn varieties are the objectives of our study as stated earlier. Since it is a problem of multi-objective optimization, the Goal programming technique has been selected. As Goal Programming is a major decision making technique used to tackle multi objective allocation problems [6], various researchers have applied it to their respective case studies [7].

The procedure followed in goal programming is to establish a specific numeric goal for each of the objectives, formulate an objective function for each objective and then seek a solution that minimizes the weighted sum of deviations of these objective functions from their respective goals.

2. MODEL FORMULATION

El Mogahzy [3] has outlined the methodology for solving this cotton-mixing problem. His assumptions hold good in our study also. Mathematical formulation of a Goal Programming model is based on linearity i.e. linear forms of both objective functions and constraints. Another assumption is certainty, which implies that parameters such as costs and average levels of quality are known with certainty.

While formulating the model, the proportion of particular cotton to be used in the mix is taken as decision variable. Associated with this, sets of constraints that may be expressed are, minimum quality requirements of fibers, minimum cotton cost and maximum yarn quality (CSP) expected. The fiber length (short and long), fiber strength and fiber fineness are taken as quality constraints of fibers. Constraints may take the form of an equation or an inequality depending on the nature of constraint. In the case of cotton mixing an obvious constraint is, the sum of proportions of cotton fibers is unity.

The goal constraints are:

1. Lower bound on Yarn quality can be stated as

$$Q_{min} = \sum_{i=1}^{k} (Q_i X_i) - y_1^+ + y_1^- \qquad (2.1)$$

2. Upper bound on Cotton cost can be expressed as

$$C_{max} = \sum_{i=1}^{k} (C_i X_i) - y_2^+ + y_2^- \qquad (2.2)$$

3. Allowable Fiber length not to exceed the limit of

$$FL_{min} = \sum_{i=1}^{k} (FL_i X_i) - y_3^+ + y_3^- \qquad (2.3)$$

4. Allowable fiber strength not to exceed the limit of

$$FS_{min} = \sum_{i=1}^{k} (FS_i X_i) - y_4^+ + y_4^- \qquad (2.4)$$

5. Allowable Fineness (Micronaire) not to exceed the limit of

$$MC_{min} = \sum_{i=1}^{k} (MC_i X_i) - y_5^+ + y_5^- \qquad (2.5)$$

Where,

i = 1,2…k : ('k' represents cotton varieties. For each count group, the maximum number of cotton varieties can be five as recommended by SITRA)

FL_i : Fiber Length of variety $_i$
FS_i : Fiber Strength of variety $_i$
MC_i : Fiber Fineness of variety $_i$
X_i : Proportion of Cotton Fiber in variety $_i$
C_i : Cotton Cost of variety $_i$

The overall objective then is to choose the values of decision variables so as to

$$\text{Minimize } Z = \sum_{j=1}^{6} (W_j (y_j^- + y_j^+)) \qquad (2.6)$$

Where,

Z is the number of penalty points incurred by missing goals
W_j represents equal weights for all the six goals
y_j^-, y_j^+ are deviational variables,
j =1,2,…6 (No. of goal constraints considered in the formulations)

The data from Tables 1 and 2 are taken as inputs to the above model and solved for optimal solution using Mathematical Programming Language (MPL) software.

3. APPLICATION OF THE MODEL

The general multi-objective optimization model presented in the previous section has been considered as the base model for conducting experiments for various targeted quality values and cost. The details are presented below.

3.1 EXPERIMENT FOR COUNTS 10s

Here, five cotton varieties, namely Bengaldeshi, Comillas, Wagad, G.cot –12 and Suyodhar – 12 are considered, for producing yarn with quality representing counts 10s.

Goal 1-Desired quality value (CSP): 1580
Goal 2-Upper limit on cotton cost: Rs. 3700
Goal 3-Lower limit on fiber strength: 16 g/tex
Goal 4-Lower limit on short fiber length: 10 mm
Goal 5-Lower limit on long fiber length: 20 mm
Goal 6-Lower limit on fiber fineness: 6 µg/inch

The selected cotton varieties are Bengaldeshi, Comillas, Wagad, G.cot - 12 and Suyodhar - 12 with the CSP values of 1443, 1465, 1528, 1812, and 1813 and cost of Rupees 3684, 3695, 3796, 3865, and 3876 respectively. The other constraints like fiber strength, fiber length and fiber fineness are taken from Table 1.

Goal programming model for experiment 1

Weights considered for Goal 1 : 50
Weights considered for Goal 2 : 50
Weights considered for Goal 3 : 2
Weights considered for Goal 4 : 2
Weights considered for Goal 5 : 2
Weights considered for Goal 6 : 2

These weights are hypothetical values only.
Minimize

$$50 y_1^- + 50 y_1^+ + 2 y_2^- + 2 y_2^+ + 2 y_3^+ + 2 y_3^- + 2 y_4^+ + 2 y_4^- + 2 y_5^+ + 2 y_5^- + 50 y_6^- + 50 y_6^+ \quad (3.1)$$

Subjected to the goal constraints

$$1443X_1 + 1465X_2 + 1528X_3 + 1812X_4 + 1813 X_5 + y_1^- - y_1^+ = 1580 \quad (3.2)$$

$$15X_1 + 16X_2 + 16X_3 + 16X_4 + 18X_5 + y_2^- - y_2^+ = 16 \quad (3.3)$$

$$9X_1 + 9X_2 + 11X_3 + 11X_4 + 11X_5 + y_3^- - y_3^+ = 10 \quad (3.4)$$

$$18X_1 + 19X_2 + 21X_3 + 23X_4 + 23X_5 + y_4^- - y_4^+ = 20 \quad (3.5)$$

$$7X_1 + 8X_2 + 6X_3 + 5X_4 + 5X_5 + y_5^- - y_5^+ = 6 \quad (3.6)$$

$$3684X_1 + 3695X_2 + 3796X_3 + 3865X_4 + 3876 X_5 + y_6^- - y_6^+ = 3700 \quad (3.7)$$

In the above formulation X_1, X_2, X_3, X_4 and X_5 are decision variables representing proportions of cotton varieties to be mixed, which vary between 0 and 1. Using MPL software, the developed model is solved and results are presented in Table 3. These results indicate optimal mix of cotton fibres namely Bengaldeshi, Comillas, Wagad, G.cot - 12 and Suyodhar - 12 with a proportion of 0.451867, 0.049752, 0.045137, 0.070308 and 0.382936 will result in minimum cost of Rs 3700 per 100 kg of cotton and maximum quality of 1580 CSP.

3.2 SENSITIVITY ANALYSIS

This analysis yields the range over which values of given parameter of the problem may vary without altering nature of final solution. The first kind of sensitivity analysis is for cost coefficients. Cost range for cotton varieties are given in Table 4.

For example, as shown in Table 4, the cost range for cotton variety Bengaldeshi is from Rupees 3634 to Rupees 3734. This means that for this range, proportions of cotton varieties Bengaldeshi, Comillas, Wagad, G.cot - 12 and Suyodhar - 12 with a proportion of 0.451867, 0.049752, 0.045137, 0.070308 and 0.382936, respectively will remain unchanged. At a cost outside the sensitivity range, different proportions will result.

Sensitivity analysis for the target values of constraints shows the range over which a value of the targeted constraint can be varied without changing set of variables that is part of the solutions. For example the sensitivity range for fiber strength is 13g/tex to 17g/tex. This means that the targeted constraint should remain in this range to keep the same decision variables in the solution. If the value of fiber strength is changed to 18 g/ tex the analysis will yield different cotton proportions.

Similarly the above multi-objective optimization model was run for a specific group of cottons for selected varieties of yarn (counts), under a selected combination of desired quality level and a targeted cost.

3.3 EXPERIMENT FOR COUNTS 20s

In case of counts 20s, the model has been run for a desired quality value (CSP) of 1830 and cost of Rs 3980. Constraints like fiber strength, fiber length and fiber fineness are taken from Table 1, and these values are incorporated in equations (3.1) to (3.6).

The results from this model presented in Table 5 indicate, to mix the cotton fibers Digvijay (Maha), G. cot - 12, J – 34, Jayadhar and Wagad in a proportion of 0.081904, 0.508097, 0.120754, 0.184843 and 0.104402, respectively.

3.4 EXPERIMENT FOR COUNTS 30s

Similarly for the counts 30s, the model has been run for a desired quality value (CSP) of 2120 and cost of Rs 5300. The results from this model presented in Table 6 indicate, to mix the cotton fibers Digvijay (Guj), F - 414, LRA – 5166, MECH and Laxmi in a proportion of 0.06970, 0.36900, 0.14890, 0.15880 and 0.25360, respectively. In a similar way the model is run for several combinations of desired quality and cost levels.

4. CONCLUSIONS

One of the major problems faced by the spinning mill managers is to regulate the inventory of raw material, the cotton. Since several cotton varieties are available in the market, the manager has an option to select the desired varieties for maximum quality and minimum cost.

In this paper an attempt has been made to study on the optimum mixing of different cotton varieties for the desired level of yarn quality. Though we have presented here only a sample of results, there is a possibility of running the model for different combinations of cotton varieties and all the counts listed in Table 1 and Table 2. These results can be presented as a Database for the proposed Decision Support System (DSS).

The cotton varieties are purchased at different times of the year, taking advantage of favorable market conditions of price and availability of desirable cotton qualities. The results of this work can be useful in cotton purchasing decisions and as a controlling tool in the raw material inventory.

There is a scope to develop a DSS, which will help the cotton mill managers to select optimal combinations of different cotton fibers available in the market, for a selected level of quality and cost. Work in this direction is in progress.

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Table 1. Varieties of Cotton and Properties

Name of the Cotton Fibers (Varieties)	Short Fiber Length (mm)	Long Fiber Length (mm)	Fiber Strength (g/tex)	Micronaire (μg/inch)	Quality (CSP)	Cotton cost For 100 kg(Rs)
Bengal deshi	18	9	15	7	1443	3684
Comillas	19	9	16	8	1465	3695
Wagad	21	11	16	6	1528	3796
G.cot.12	23	11	16	5	1812	3865
Suyodhar 12	23	11	18	5	1813	3876
F414	23	12	20	4	2117	4988
Digvijay (maha)	24	12	21	4	2242	4316

Table 1. (Contd…)

Name of the Cotton Fibers (Varieties)	Short Fiber Length (mm)	Long Fiber Length (mm)	Fiber Strength (g/tex)	Micronaire (µg/inch)	Quality (CSP)	Cotton cost For 100 kg(Rs)
V-797	24	11	18	4	1859	4049
Jayadhar	24	11	18	5	1837	4059
J-34	24	11	19	4	2000	4555
Bikareri narma	25	12	19	4	2102	4556
H-777	25	12	21	4	2158	4673
SRT-1(maha)	25	12	18	4	1906	4888
NHH44	26	12	21	4	2271	5521
Digvijay(Guj)	25	12	25	4	2277	5638
G.cot.13	26	13	18	5	1818	5378
Laxmi	26	12	18	4	1977	5466
G.agethi	27	13	19	4	2018	5544
1007	28	12	22	4	2186	5655
MCU-7	28	13	20	4	2135	5787
MECH	29	14	21	4	2263	5624
LRA-5166	29	14	20	4	2145	5287
Sankar4	30	14	22	4	2301	7067
JKHY1	30	15	21	4	2166	5566
MCU7	30	14	22	3	2465	7171
Sankar6	30	15	21	4	2053	5765
Hybrid4	30	14	20	4	2022	5482
MCU5	32	15	21	3	2331	7249
DCH32(kar)	34	16	23	3	2514	9836
Suvin	36	18	30	3	2673	9950

Table 2 Groupings of Cotton Varieties for Different Counts

Group No.	Counts	Cotton Varieties
1	Up to 10s	Bangladeshi, Comillas, Wagad
2	11s – 20s	Jayadhar, Digvijay (Maha), Wagad, G.cot.12, Suyodhar12, j-34
3	21s – 30s	Digvijay (Guj), F414, MECH, Laxmi, LRA-5166, V -797
4	31s – 40s	1007, MCU-7, Sankar-4, G. Agethi,G.cot.13,
5	41s – 80s	Sankar-6, Hybrid-4, JKHY-1, MCU-7, NHH44
6	81s – 120s	Suvin, DCH -32(kar), MCU-5 (TN)

Table 3 Optimal Proportions of Cotton Varieties for Counts 10s (Experiment 1)

Specified Goal values Minimum Quality (CSP) - 1580	Max. Cost Rs. 3700	
Decision Variables X_j	**Name of the fiber**	**Proportions**
X_1	Bengaldeshi	0.451867
X_2	Comillas	0.049752
X_3	Wagad	0.045137
X_4	G. Cot - 12	0.070308
X_5	Suyodhar - 12	0.382936

Table 4 Cost Range for Cotton Varieties

Types of Cotton	Target Cost (Rs)	Allowable Minimum Cost (Rs)	Allowable Maximum Cost (Rs)
Bengaldeshi	3684	3634	3734
Comillas	3695	3645	3745
Wagad	3796	3746	3846
G. Cot - 12	3865	3815	3965
Suyodhar - 12	3876	3926	3976

Table 5 Optimal Proportions of Cotton Varieties for Counts 20s

Specified Goal values Minimum Quality (CSP) - 1830	Max. Cost Rs. 3980	
Decision Variables X_j	**Name of the fiber**	**Proportions**
X_1	Digvijay (Maha)	0.081904
X_2	G. Cot - 12	0.508097
X_3	J. 34	0.120754
X_4	Jayadhar	0.184843
X_5	Wagad	0.104402

Table 6 Optimal Proportions of Cotton Varieties for Counts 30s

Specified Goal values Minimum Quality (CSP) - 2120	Max. Cost Rs. 5300	
Decision Variables X_j	**Name of the fiber**	**Proportions**
X_1	Digvijay (Gug)	0.06970
X_2	F - 414	0.36900
X_3	LRA – 5166	0.14890
X_4	MECH	0.15880
X_5	Laxmi	0.25360

