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Key Variables in the Control of Lead Time in Spinning Mills

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Abstract
An investigation of various factors which affect the lead time in spinning mills which produce 14.76 tex (40 Ne) carded yarns linear density is reported. For this study, data were collected from 27 mills producing 14.76 tex carded yarns of linear density. The important parameters which affect the lead time were obtained by principal component analysis of the data. Correlation matrix and multiple regression analysis were carried out taking into account the lead time as the dependent variable and HOK (the number of Operative Hours required to produce 100 kg of yarn), FQI (Fibre Quality Index), YQI (Yarn Quality Index) and spindle production as independent variables. The reliability of the data was checked by Cronbach's alpha, which indicated 0.839. Other tests such as the Kruskal-Wallis test, Durbin Watson test, KMO (Kaiser – Meyer Olkin) and Bartlett's test were also done to find out their association. The results show that of all the parameters considered the, lead time exerts maximum influence on spindle production, HOK and the yarn quality index in carded counts.

Key words: *carded, HOK, lead time, spindle production, yarn quality index.*

Introduction

India is the second largest world's producer of textiles and garments. The Indian textile industry accounts for about 24% of the world's spindle capacity and 8% of the global rotor capacity. The textile industry has made a major contribution to the national economy in terms of direct and indirect employment generation and net foreign exchange earnings. The sector contributes about 14% to industrial production, 4% to the gross domestic product (GDP), and 27% to the country's foreign exchange inflows. Moreover it provides direct employment to over 45 million people and is the second largest provider of employment after agriculture. Thus the growth and all round development of this industry has a direct bearing on the improvement of India's economy.

In India, there are 3103 spinning mills consisting of 44.17 million spindles. Most of the spinning mills are located near the cotton growing areas and India has achieved a yield of 400 lakh bales recently, which is an all time record. Hence, it is imperative that in order to make spinning mills viable, a considerable amount of thought is bestowed on supply chain management. Although the supply chain management concept is little known among the management of spinning mills, awareness of it is scant. Hence it is most appropriate to apply the concept of supply chain management in order to derive maximum advantage from cotton that has been grown. It should noted that the supply chain partners are cotton producers, ginners, yarn suppliers, manufacturers, wholesalers and retailers. It goes without saying that utmost co-operation among them will lead to tangible benefits to all. Increasing competition in the textile market will bring viable and sustainable supply chain management. It is a well known fact that the success of a spinning mill depends on quality products at a low cost in a timely manner. It is very important to know the demands of the customers and also the range of the products that are manufactured in order to forecast the requirements for effective supply chain collaboration. It is noticed that, although a number of studies have been made on supply chain management in the Indian textile industry, most of them deal with the garment industry and also general aspects of competitive advantage. There are no papers published on the measurement of supply chain management with reference to spinning mills in depth.

The supply chain of textiles consists of fibre production, yarn spinning, fab-

Table 1. *Various sequences of processes*

Blow room	Carding	Drawing	Simplex	Ring frame	Winding	Supply	→ 1
Blow room	Chute feed	Drawing	Simplex	Ring frame	Winding	Supply	→ 2
Blow room	Chute feed	Drawing	Simplex	Ring frame 1008 spindles	Winding	Supply	→ 3

ric manufacturing, textile wet processing, garment production and retailing of the different steps. Spinning involves the conversion of fibres to yarn and marketing it to powerlooms & handlooms and for the colouring and manufacture of sewing threads. Thus this sector seeks solutions to achieve “sustainable” and reduced lead times by implementing measures to find out the inter-dependency of various parameters. Hence the production of yarns is not adequate until all the parameters that affect it are controlled.

The sequence of processes which will result in a reduced lead time are given in ***Table 1***.

Of the three cases in ring spinning, it is apparent that the third case merits consideration as it is found to be favourable.

Review of literature

Lead time refers to the number of days which are quoted by mills required to fulfill an order of 20,000 kgs of yarn. This varies from count to count and also the type of technology that is used for producing the yarn. External factors such as shortage of cotton, breakdown of machinery, shortage of labour, heavy absenteeism, process organisation, automation of the machines, their technical state, air - conditioning, qualifications of the personnel, allocation of a higher number of machines and product customization will also affect the lead time. Because of the importance of this factor in spinning and garment industries, a great deal of work has been carried out on it by modelling it and commenting on the reasons for long lead time in the garment industry.

As pointed out by Lam and Postle [1], the typical problems facing a textile supply chain in Hong Kong are short product cycles for fashion articles, long production lead – times and minimum batch sizes from customers. Also Leung [2] highlighted the importance of lead time and felt that the employment of several factories to produce one style would shorten it. Nuruzzaman, Haque and Ahasanul [3] discussed lead time management in the garment sector and analysed the various factors which will result in minimum lead time. There are many papers which discuss lead time and its importance in a general manner [4 - 9]. This subject has also been dealt with recently by Vanathi and Swamynathan [10].

Research objectives

- To identify the key variables which affect supply chain management and lead time in spinning mills producing carded counts.
- To find out the inter-relationship between the lead time and variables in a spinning mill in respect of the carded count.

Since a number of mills produce 14.76 tex (40 Ne) carded count linear density, this was selected. This yarn has a good export market.

The selection of the parameters is based on the fact that the spindle production and lead time in a spinning mill are affected by such factors as the quality of the raw material, the process plan for producing yarns, the number of operative hours to produce 100 kgs of the material (HOK), machine utilisation, end breaks, the yarn quality index and spinning plan. The fibre quality index, which encompasses the fibre length, fineness strength and maturity, is an important parameter affecting yarn production.

It is given by the following formula.

$$FQI = \frac{LSM}{f} \quad (1)$$

where, L = 50% span length in mm, S = bundle strength tested on HVI expressed in g/tex, M = maturity ratio measured by Shirley FMT, f = fibre linear density (micronaire value).

Machine utilisation affects yarn production. Also the spin plan affects the lead time as the parameters of speed, twist and production capacity influence spinning production. Since a number of parameters have been considered, it was thought desirable to use the correlation technique as the most appropriate to find out their association.

The yarn quality index (*YQI*) was calculated using Barella et al’s [11] formula

$$YQI = \frac{T \text{ x } E}{\text{U}} \quad (2)$$

where, T = yarn tenacity in cN/tex, E = yarn elongation in %, U = yarn unevenness in %.

Research methodology

The following methodology was applied in the analysis of the results.

A. Cronbach’s alpha

Cronbach’s alpha is a measure of internal consistency, that is, how closely related a set of items are as a group [12].

A reliability coefficient of 0.70 or higher is considered “acceptable” in most scientific research.

This was calculated for data obtained for 27 mills.

Suppose a quantity is measured which is a sum of K components (K-items)

$$X = Y_1 + Y_2 + \ldots.. Y_K$$

Cronbach’s α is defined as

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K} \sigma_{Yi}^2}{\sigma_X^2}\right) \quad (3)$$

where, σ_x^2 is the variance of the total test scores observed, and $\sigma_{Y_i}^2$ is that of component i for the current sample of persons.

B. Multiple regression

This analysis was done taking into account the lead time as the dependent variable and the fibre quality index, yarn quality index, HOK, and spindle production as the independent variables.

C. Kruskal – wallis test

This is a non-parametric test which is done to find out the significance of the various parameters, namely the fibre quality index, yarn quality index, HOK and spindle production.

In this method, the test statistic is given by

$$K = (N-1)\left(\frac{\sum_{i=1}^{g} n_i \left(\overline{r_i} - \overline{r}\right)^2}{\sum_{i=1}^{g} \sum_{j=1}^{ni} \left(r_{ij} - \overline{r}\right)^2}\right) \quad (4)$$

where, n_i is the number of observations in group i, r_{ij} is the rank (among all observations) of observation j from group i, N is the total number of observation across all groups, $\overline{r_i} = \frac{\sum_{j=1}^{ni} r_{ij}}{n_i}$ $\overline{r} = \frac{1}{2}(N+1)$ is the average of the r_{ij}.

D. Durbin – Watson test

This test was carried out to find out the autocorrelation (the relationship between values separated from each other by a given time lag) in the residuals from a statistical regression analysis. The Durbin – Watson statistic always lies between 0 and 4. A value of 2 indicates that there is no autocorrelation between the samples. Values approaching zero indicate a positive auto correlation while values towards 4 indicate a negative auto correlation.

If e_t is the residual associated with the observation at time t, then the test statistic is

$$d = \frac{\sum_{t=2}^{T} \left(e_t - e_{t-1}\right)^2}{\sum_{t=1}^{T} e_t^2} \qquad (5)$$

where, T is the number of observations and d the Durbin – Watson test.

E. KMO – Bartlett's test

KMO (Kaiser – Meyer - Olkin) & Bartlett's test of sphericity is a measure of sampling adequacy that is recommended to check the case of the variable ratio for the analysis being conducted. In most academic and business studies, KMO & Bartlett's test play an important role in accepting the sample adequacy. While the KMO ranges from 0 to 1, the world over accepted index is over 0.6. Also Bartlett's test of sphericity relates to the significance of the study, showing the validity and suitability of the responses connected to the problem being addressedby the study. For the factor analysis to be recommended suitable, Bartlett's test of sphericity must be less than 0.05.

The overall KMO index is computed as ***Equation 6***

$$KMO = \frac{\sum_{i}\sum_{j\neq i} r_{ij}^2}{\sum_{i}\sum_{j\neq i} r_{ij}^2 + \sum_{i}\sum_{j\neq i} a_{ij}^2}$$

$$x^2 = -\left(n - 1 - \frac{2p+5}{6}\right) xIn\,|R| \qquad (6)$$

where, a_{ij} is partial correlation matrix, r_{ij} is correlation matrix.

Bartlett's test statistic uses the following formula

$$x^2 = -\left(n - 1 - \frac{2p+5}{6}\right) xIn\,|R| \qquad (8)$$

where, n is number of samples, p is variables, R is correlation matrix.

F. Communalities

Communalities indicate the amount of variance in each variable that is accounted for.

Table 2. *Actual data 14.76 tex carded yarn linear density, *For producing 20000 kgs of yarn.*

Mill No.	Fibre Quality Index	Roving Production, kg/spl/shift	CSP (Count Strength Product)	Yarn realisation, %	Spindle Production, gms/spl/shift	Top arm roller pressure – front, (Kg)	Top arm roller pressure – middle, kg	Top arm roller pressure – back, kg	End breaks, 100 spindle / hour	UKG, units/kg of yarn	HOK	Yarn Quality Index	Machine utilisation, %	*Lead time, days
1	71	3	2300	90	97	20	18	12	6	3.5	12.0	14.91	80	4.0
2	90	2.7	2500	86	110	18	14	16	10	3.6	22.0	15.53	80	2.0
3	68	3.32	2450	85	98	14	15	9	6	4.12	18.0	3.60	81	20.0
4	68	3.3	2450	85	115	18	20	20	9	3.7	25.0	11.10	97	6.0
5	80	4.2	2350	87	105	16	12	14	8	3.75	18.0	11.00	88	8.0
6	94	3	2400	85	80	18	16	12	7	3.1	11.5	3.27	94	22.0
7	82	4.6	2700	85	106	16	12	16	3	3	19.0	8.64	96	10.0
8	77	3.85	2200	88	116	18	16	12	8	3.2	12.0	5.78	98	10.0
9	82	4.8	2600	85.2	114	14	10	12	6.2	3.1	13.0	6.31	96.5	6.0
10	56	1.95	2300	84	83	19	20	22	12	2.7	18.0	6.33	90	25.0
11	80	6.8	2600	84	100	18	12	12	9	4	18.0	5.23	98.3	15.0
12	73	4.62	2320	86	115	16	12	14	10	4.1	18.0	5.90	96	7.0
13	92	4.5	2400	86	85	25	28	30	5.2	3.4	12.0	8.01	95	10.0
14	60	3.5	2600	87.13	110	16	18	16	8.2	2.8	22.0	10.02	95	18.0
15	77	3.8	2500	86	110	15	13	15	5	3.8	13.0	6.75	85	14.0
16	75	3.93	2450	84	112	15	13	15	5	3.7	20.0	3.69	98	7.0
17	65	4.8	2400	83	115	16	14	14	7	2.9	28.0	7.27	87	15.0
18	75	1.8	2300	80	130	14	12	12	9	5	38.0	6.85	90	10.0
19	65	2.77	2000	86.5	80	16	12	18	15	2.7	18.0	4.04	96	20.0
20	69	2.8	2200	87	88	18	16	14	14	3.2	22.0	6.42	90	15.0
21	74	3	2200	90	75	18	16	14	12	3	20.0	11.68	95	20.0
22	78	1.85	2200	89	72	23	18	16	26	3.05	37.8	3.40	95	30.0
23	70	2.7	2200	89	78	14	12	14	14	3.5	36.0	2.32	72	36.0
24	67	2.7	2200	87	75	14	12	14	17	3.8	40.0	3.32	72	36.0
25	90	2.6	2300	87	80	18	16	16	8	3	30.0	2.70	97	30.0
26	140	5.83	2500	85	103	18	12	16	8	4.3	30.0	14.62	96	5.0
27	75	6	2800	86	115	14	10	14	6	4.5	15.0	15.89	95	3.0
Mean	**77.51**	**3.66**	**2385.93**	**86.03**	**98.78**	**17.00**	**14.78**	**15.15**	**9.39**	**3.50**	**21.71**	**7.58**	**90.84**	**14.96**
SD	**15.62**	**1.27**	**180.92**	**2.17**	**16.54**	**2.70**	**3.88**	**3.98**	**4.74**	**0.58**	**8.62**	**4.16**	**7.77**	**9.88**
SE	**3.01**	**0.25**	**34.82**	**0.42**	**3.18**	**0.52**	**0.75**	**0.77**	**0.91**	**0.11**	**1.66**	**0.80**	**1.50**	**1.90**
Cronbach alpha = 0.839														

Table 3. *Correlation analysis (Actual data) – 14.76 tex (40 Ne) carded yarn, * Significant at 5% level, ** Significant at 1% level.*

S. No	Parameters	Pearson correlation coefficient
1	Roving production (kg/spl/shift) vs CSP	0.658**
2	Roving production (kg/spl/shift) vs spindle production (gms/spl/shift)	0.413*
3	Roving production (kg/spl/shift) vs end breaks / 100 spindle / hour	-0.511**
4	**Roving production (kg/spl/shift) vs lead time (days)**	**-0.508****
5	CSP (Count strength product) vs spindle production (gms/spl/shift)	0.545**
6	CSP (Count strength product) vs end breaks / 100 spindle / hour	-0.630**
7	CSP (Count strength product) vs YQI	0.432*
8	**CSP (Count strength product) vs lead time (days)**	**-0.513****
9	Yarn realisation (%) vs UKG (units / kg of yarn)	-0.390*
10	Spindle production (gms/spl/shift) vs end breaks / 100 spindle / hour	-0.585**
11	**Spindle production (gms/spl/shift) vs lead time (days)**	**-0.762****
12	End breaks / 100 spindle / hour vs HOK	0.597**
13	**End breaks / 100 spindle / hour vs lead time (days)**	**0.605****
14	**HOK vs lead time (days)**	**0.521****
15	**Yarn Quality Index (YQI) vs lead time (days)**	**-0.688***

G. Rotated component matrix

The rotated component matrix gives an idea of the pattern of factor loadings. Variables with higher loadings are considered to be more important since they have a greater influence on the factors selected.

Results and discussion

Table 2 (see page 141) gives the raw data collected. The relationships between the variables included in ***Table 3*** are illustrated in ***Figures (1 – 15).*** Multiple regression analysis was performed for the data. The results of the multiple regression analysis are given in ***Table 4.*** In this analysis, the dependent variable

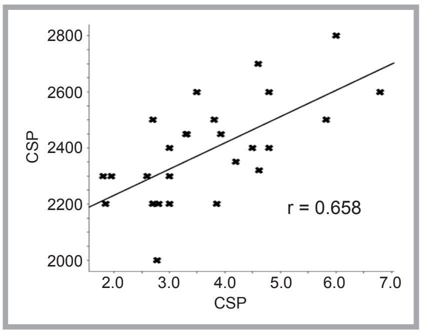

Figure 1. *Relationship of roving production in kg/spl/shift & CSP.*

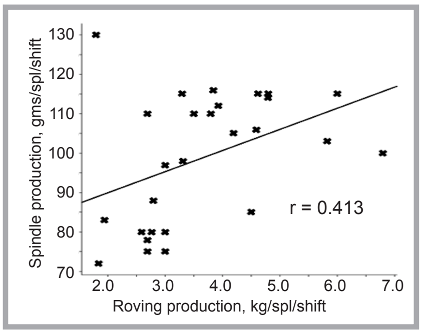

Figure 2. *Relationship of roving production in kg/spl/shift & spindle production in gms/spl/shift.*

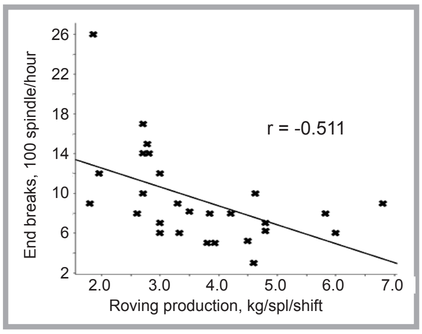

Figure 3. *Relationship of roving production in kg/spl/shift & end breaks in 100 spindle/hour.*

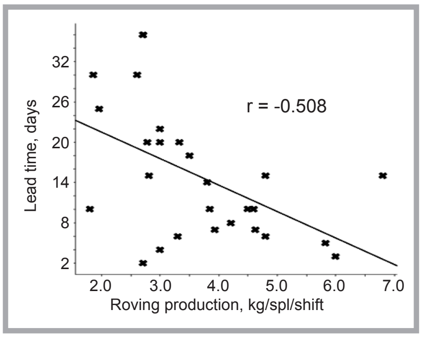

Figure 4. *Relationship of roving production in kg/spl/shift & lead time in days.*

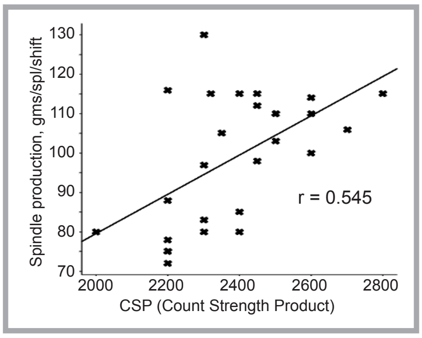

Figure 5. *Relationship of CSP & spindle production in gms/spl/shift.*

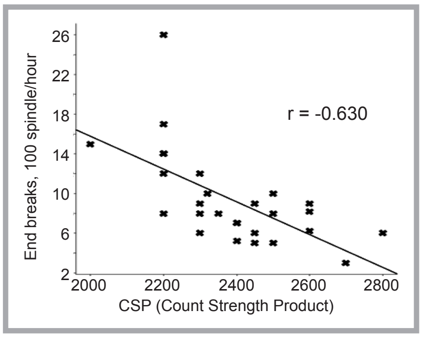

Figure 6. *Relationship of CSP & end breaks in 100 spindle/hour.*

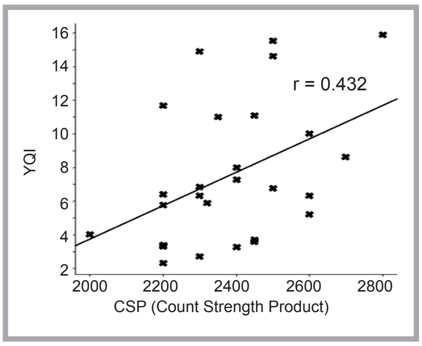

Figure 7. *Relationship of CSP & YQI.*

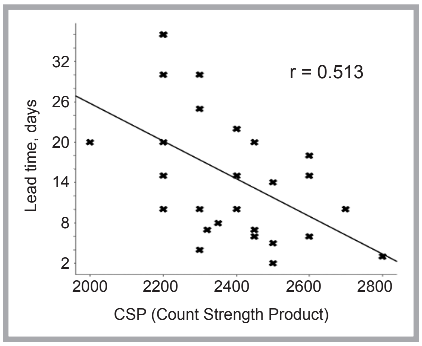

Figure 8. *Relationship of CSP & lead time in days.*

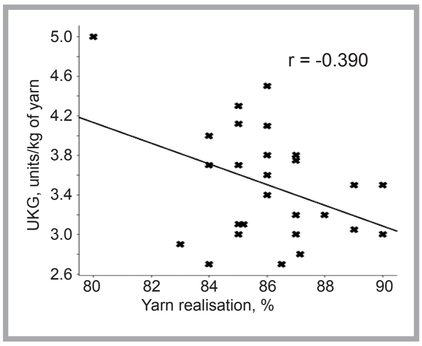

Figure 9. *Relationship of yarn realisation in % & UKG in units/kg of yarn.*

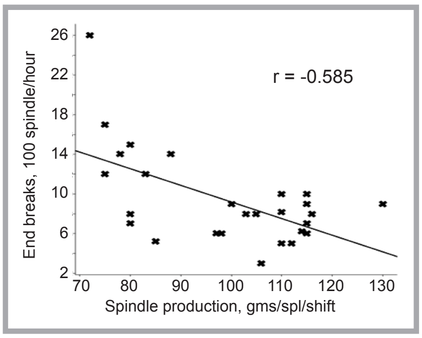

***Figure 10**. Relationship of spindle prodction in gms/spl/shift & end breaks in 100 spindle/hour.*

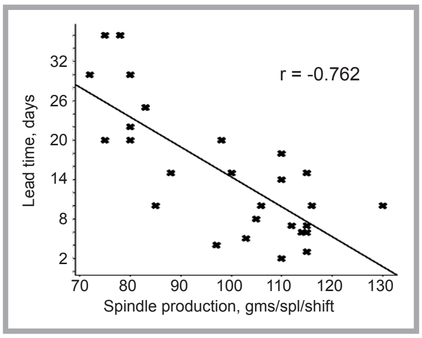

***Figure 11.** Relationship of spindle production in gms/spl/shift & lead time in days.*

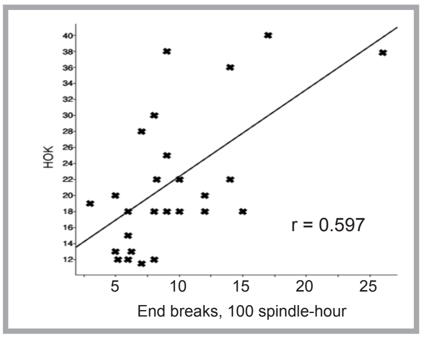

***Figure 12.** Relationship of end breaks in 100 spindle/hour & HOK.*

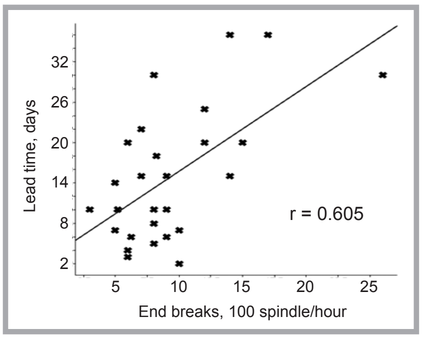

***Figure 13.** Relationship of end breaks in 100 spindle/hour & lead time in days.*

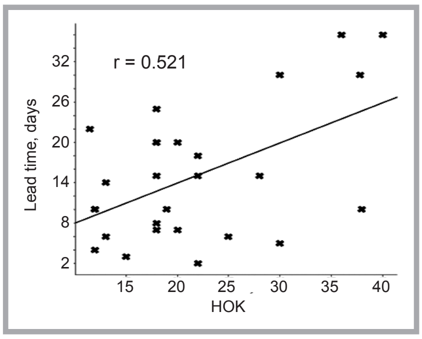

***Figure 14.** Relationship of HOK & lead time in days.*

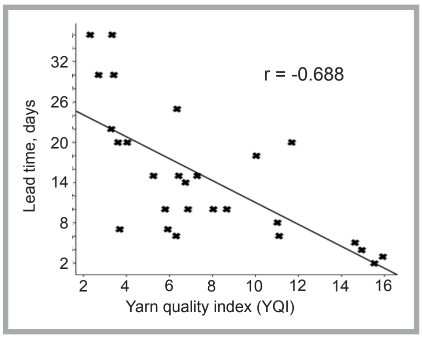

***Figure 15.** Relationship of Yarn Quality Index (YQI) & lead time in days.*

is the lead time, while independent variables are HOK (Number of operative hours required to produce 100 kg of yarn), the fibre quality index (FQI), yarn quality index (YQI) and spindle production. The reliability of the data was checked by Cronbach's alpha, which was found to be 0.839.

Tables 2 gives details of parameters collected from 27 spinning mills producing 14.76 tex (40 Ne) carded yarn, from which it can be seen that there is a wide variation in spindle production and lead time. Spindle production ranges between 72 to 130 and the lead time ranges between 2 to 36.

The reliability of the data was tested using Cronbach's alpha method and found to be above 0.7, which is acceptable.

Table 3 gives the correlation matrix between the various parameters for 14.76 tex (40 Ne) carded yarns, from which it is apparent that a very strong correlation between roving production and CSP, roving production and spindle production, roving production and end breaks, roving production and lead time, CSP and spindle production, CSP and end breaks, CSP and YQI, CSP and lead time, yarn realisation and UKG, spindle production and end breaks, spindle production and lead time, end breaks and HOK, end breaks and lead time, HOK and lead time, YQI and lead time was obtained. The factors which affect the lead time are indicated in bold letters in ***Table 3***.

Figures (1 –15) show the relationship between the various parameters for the count considered in the study and their correlation coefficients.

In order to find out the dependence of the lead time on the fibre quality index, the spindle production, HOK, yarn quality index and multiple correlation coefficient was computed.

It is interesting to note that the yarn quality index has a strong effect on the lead time ***(Table 4)***.

The relative importance and contribution of parameters are approximately given below:

X_1 → 11.5% decrease
X_2 → 33.5% decrease
X_3 → 38% increase
X_4 → 81.9% decrease

***Table 4.** Regression analysis – 14.76 tex (40 Ne) carded yarn linear density. **Note:** ** - $p < 0.01$; * - $p < 0.05$.*

S. No.	Variables	Coefficient	SE	T	'p' Value
	(Constant)	54.961			
1	**Fibre quality index**	-0.115	0.05	-2.438	0.023*
2	**Spindle production**	-0.335	0.05	-7.234	0.000**
3	**HOK**	0.380	0.08	4.481	0.000**
4	**Yarn quality Index**	-0.819	0.19	-4.204	0.000**
	R value	**0.943**			
	R^2 value	**0.889**			
	F value	**44.127****			
	Durbin watson test	**1.996**			

*Table 5. Kruskal – Wallis test: 14.76 tex carded yarn linear density. **Note**: ** p < 0.01, * p < 0.05.*

Variables	Lead time	Number	Mean Rank	Chi-square	DF	'p' Value
Fibre quality index	Upto 7	8	15.94	7.023	2	0.030*
	8-24	14	13.86			
	Above 24	5	11.30			
	Total	**27**	**13.70**			
Spindle production	Upto 7	8	19.31	11.157	2	0.004**
	8-24	14	14.43			
	Above 24	5	4.30			
	Total	**27**	**12.68**			
HOK	Upto 7	8	12.75	6.066	2	0.048*
	8-24	14	11.93			
	Above 24	5	21.80			
	Total	**27**	**15.49**			
Yarn Quality Index	Upto 7	8	19.25	9.939	2	0.007**
	8-24	14	14.21			
	Above 24	5	5.00			
	Total	**27**	**12.82**			

Based on the facts above, a model of the multiple linear regression analysis for the dependent variable lead time and independent variables (fibre quality index, spindle production, HOK and yarn quality index) is proposed. The correlation between the lead time and other variables is strong.

Lead Time (Y) = 54.961 - 0.115 (FQI) +
– 0.335 (Spindle Production) +
+ 0.380 (HOK) +
– 0.819 (Yarn Quality Index)

The Durbin Watson test shows a value of more than 1 (***Table 4***), which indicates that all the variables are significant (Fibre Quality Index, Spindle Production, HOK, Yarn Quality Index).

By means of non- parametric tests such as the Kruskal – Wallis, the association between the variables is determined ***(Table 5).***

The Kruskal – Wallis test shows that the values are significant for the variables considered.

The Kaiser-Meyer-Olkin test and Bartlett's test also show a highly significant value, which implies that the variables considered are most appropriate ***(Table 6)***.

*Table 6. KMO and Bartlett's test – 14.76 tex (40 Ne) carded yarn linear density. **Note**: ** Significant at 1% level.*

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.567
Bartlett's Test of Sphericity	Approx. Chi-Square	224.760
	DF	91
	Sig.	0.000**

The communalities given in ***Table 7*** show that the fibre quality index, yarn quality index, lead time and HOK are the most important variables to be considered.

Table 8 gives the rotated component matrix, which shows that 24.84% of the variance comprising HOK, spindle production, end breaks, top arm roller pressure (front), top arm roller pressure (middle), top arm roller pressure (back) and machine utilisation are the principal parameters.

Roving production accounts for 19.290% of the variance. CSP, the Yarn Quality Index and Yarn Realisation account for 13.893% of the variance. The other parameters, namely the lead time and UKG, account for 11.509% of the variance and the Fibre Quality Index for 10.708% of the variance.

Conclusion

The results show that the lead time is significantly influenced by YQI and HOK. Assessment of the spinning organisation in spinning mills demonstrated a wide variation in many of them with respect to many parameters. The inter-relationship between the lead time and key variables and the optimisation of these is imperative for achieving reduced lead times and a better supply chain in spinning mills.

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Table 7. Communalities – 14.76 tex (40 Ne) carded yarn linear density.

Variables	Initial	Extraction
FQI	1.000	0.824
Roving production	1.000	0.752
CSP	1.000	0.632
Yarn realisation	1.000	0.899
Spindle production	1.000	0.842
Top arm roller pressure front	1.000	0.886
Top arm roller pressure middle	1.000	0.889
Top arm roller pressure back	1.000	0.766
End breaks	1.000	0.728
UKG	1.000	0.752
HOK	1.000	0.842
YQI	1.000	0.855
Machine utilisation	1.000	0.714
Lead time	1.000	0.853

Table 8. Rotated component matrix - 14.76 tex (40 Ne) carded yarn linear density.

No.	Variables	Ring frame condition	Process parameters in roving	Quality parameters	Multiple effect of all parameters	Raw material effect
1	HOK	0.847				
2	Spindle production	0.595				
3	End breaks	0.802				
4	Top arm roller pressure-front	0.856				
5	Top arm roller pressure-middle	0.915				
6	Top arm roller pressure-back	0.870				
7	Machine utilisation	0.580				
8	Roving production		0.621			
9	CSP			0.650		
10	YQI			0.777		
11	Yarn realisation			0.920		
12	Lead time				0.740	
13	UKG				0.542	
14	FQI					0.886
	Initial Eigen values	**4.621**	**2.876**	**1.367**	**1.258**	**1.111**
	% of variance	**24.840**	**19.290**	**13.893**	**11.509**	**10.708**
	Cumulative %	**24.840**	**44.130**	**58.023**	**69.531**	**80.240**

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