K.T. Anand[1], A. John Rajan[2], B.R. Ramesh Bapu[3]

Development of a Method to Compute the Overall Key Performance Index for a Spinning Mill to Aid Supply Chain Management

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[1] **Panimalar Polytechnic College, Department of Mechanical Engineering,** Chennai – 29, India, e-mail: ktanandppc@gmail.com

[2] **VIT University, Department of Manufacturing Engineering, SMEC,** Vellore, India, e-mail: ajohnrajan@gmail.com

[3] **Chennai Institute of Technology,** Kundratur, Chennai – 69, India, e-mail: brrbapu.aero@gmail.com

Abstract

This paper aims to provide a convenient measure of evaluating the performance of spinning mills using the overall Key Performance Index. Although many authors have advocated the concept of the key performance index, their studies were confined to departments other than spinning. The methodology followed in this paper is based on providing weightages to machine utilisation, spindle production, end breaks, HOK (number of operative hours required to produce 100 kg of yarn), roving production, yarn realisation, CSP (count strength product), units/kg of yarn and to compute the overall Key Performance Index in a logical manner. It has come to light that some mills have achieved an overall Key Performance Index (OKPI) of more than 100 and less than 100 in certain other mills. Also the important factors which are significant for supply chain management have been highlighted. A very useful source of information and advice for various spinning mills to develop their own supply chain strategies is provided. Especially with the introduction of technical textiles, supply chain management has become a critical area.

Key words: *key performance index, overall KPI.*

Introduction

Monitoring supply chain performance in the textile industry is of great assistance in identifying potential problems and improving performance. A number of papers have dealt with this subject (Lam and Postle [22]), Gunasekaran et al. [15, 16], Clift [12], Cardenas et al. [9], Thakkar et al. [32], Lenny Koh et al. [23], Jain et al. [19], Bourne et al. [7], Neely et al. [26-29], and Burgess et al. [8]. The importance of supply chain management in the spinning industry cannot be over emphasised. However, there is no proper quantification of it and whatever assessment that is being done is also empirical. Even though the terms "performance" or "efficiency" are often used, communicating the same meaning, measuring the performance or efficiency of an "enterprise" conveys different meanings altogether. One of the major objectives of supply chain planning and management is to maximise total profit in the chain rather than maximising the profit of an organisation in isolation.

There are a number of approaches for measuring supply chain performance. These are a balanced score card, the supply chain council's score model, the logistics score board, activity based costing and economic value analysis.

Prabir Jana et al. [13] addressed the measurement of the efficiency of a supply chain using the key performance index. However, their study was confined to the garment industry. Several other authors, such as Haque et al. [17], have addressed the performance evaluation of the Bangladeshi apparel and textile supply chain network. Bongsug [5] discussed the development of key performance indicators for the supply chain. Bora et al. [6] discussed the development of key performance indicators for performance controlling of the supply chain. Badawy et al. [3] addressed the performance indicators which are used in the industry. Ulle and Santosh kumar [33] carried out an analysis using the Analytical Hierarchy Process to assess the key performance indicators for TQM (Total Quality Management). Bhatti et al. [18] discussed the key performance indicators (KPI) and their impact on overall organisational performance. Sharfuddin Ahmed Khan [21] discussed the importance of measuring supply chain management performance and its need particularly in multi-criteria decision making techniques. Cai et al. [20] proposed a framework using a systematic approach for improving iterative Key Performance Indicators (KPI) accomplished in the supply chain context. The framework proposed quantitatively analyses the interdependence relationship among a set of KPIs. It can identify crucial KPI accomplishment costs and propose performance improvement strategies for decision makers in a supply chain. Lindberg et al. [10] discussed key performance indicators for improving performance. Benchmarking KPIs from similar equipment and plants is one method of identifying poor performing areas and estimating improvement potential. They feel that actions for performance measurements can be developed, prioritised and implemented based on KPI benchmarking results. Spahija et al. [30] discussed the evaluation of production effectiveness in garment companies through key performance indicators.

Spahija and Shehi [31] discussed the development of key performance indicators and impact assessment for a garment company.

The aim of this present study is to suggest suitable measures to evaluate the efficiency of supply chain management in spinning mills. Some of the findings of a supply chain management study in spinning are reported by one of the authors (Anand et al. [1]). The present paper reports the computation of the KPI in each department and the overall KPI, which will be useful for assessing the performance.

Methodology

Selection of the material

Since a large number of mills in South India produced 14.76 tex (40 Ne) carded count linear density, this was selected. This is used for knitting and has a very good export potential.

Selection and description of various parameters

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 raw material, the process plan for producing yarn, the number of operative hours to produce 100 kg of the material (HOK), machine utilisation, end breaks, the yarn quality index and the spinning plan. A questionnaire was prepared, and details of the various parameters: FQI (Fibre Quality Index), roving production, CSP (count strength product), yarn realisation, spindle production, top arm roller pressure (front), top arm roller pressure (middle), top arm roller pressure (back), end breaks, UKG, HOK (number of operative hours required to produce 100 kg of yarn), YQI (yarn quality index), machine, utilisation were collected from 31 mills producing 40 Ne (14.76 tex) carded yarn. Each parameter is the mean of 10 readings.

Details of parameters are given below:

1. FQI (fibre quality index) is a combined measure of the quality of cotton and is calculated by the following formula [2]:

   $$FQI = \frac{Lusm}{f}$$

   (the higher the FQI value, the better the performance).

   Where:
   L = Mean length, in mm (the higher the mean length value, the better the performance)
   u = Uniformity ratio, in % (the higher the uniformity ratio value, the better the performance)
   s = Bundle strength, in gm/tex (the higher the bundle strength value, the better the performance)
   m = Maturity (the higher the maturity value, the better the performance)
   f = Micronaire value, in (μg/in) (the lower the micronaire value, the better the performance)
2. CSP is a count strength product obtained by multiplying the count and strength of the yarn (the higher the CSP value, the better the performance).
3. Roving production and performance represents production on a simplex machine/spindle/shift (the higher the roving production value, the better the performance). The performance is assessed by the unevenness of the roving (the higher the value, the poorer the performance).
4. Yarn realisation is the amount of yarn obtained from cotton (the higher the yarn realisation value, the better the performance).
5. Spindle production gives the production/spindle/shift in gms (the higher the spindle production value, the better the performance).
6. Top arm roller pressure gives the pressure exerted on the front, middle and top back rollers on a ring frame. This is measured by a TARP GAUGE (top arm roller pressure gauge) (the higher the top arm roller pressure value, the better the performance).
7. End breaks/100 spindle–hours is the number of breaks which have occurred on the ring frame/hour converted to 100 spindles (the lower the end breaks/100 spindle–hours value, the better the performance).
8. UKG (units/kg of yarn) represents the electrical power utilised to produce 1 kg of yarn (the lower the UKG (units/kg of yarn) value, the better the performance).
9. HOK represents the number of operative hours needed to produce 100 kg of yarn (the lower the HOK value, the better the performance).
10. Yarn quality index (YQI) was calculated using the Barella [4] formula:

    $$YQI = \frac{T \text{ x } E}{U}$$

    (the higher the YQI value, the better the performance).
    Where,
    T = Yarn tenacity, in g/tex (the higher the yarn tenacity value, the better the performance)
    E = Yarn elongation, in % (the higher the yarn elongation value, the better the performance)
    U = Yarn unevenness, in % (the lower the yarn unevenness value, the better the performance)
11. Machine utilisation gives an overall idea of the number of spindles working on the ring frame (the higher the machine utilisation value, the better the performance).
12. Lead time gives an overall idea of the time required to convert cotton to yarn and the further testing and packing of it (the lower the lead time value, the better the performance).

Development of methodology to compute individual KPIs (key performance index)

Besides this, new measures such as the key performance index for each department and the overall KPI were performed, as suggested by Diwan et al. [13]. Details of the computation of the KPI are given below ***Equation (1).***

The standard value is taken from the norms provided by SITRA (South India Textile Research Association). It must be pointed out that the latest norms were consulted upon and calculations performed (According to SITRA Norms for spinning mills Chellamani [11]).

Development of a suitable methodology to compute the overall KPI

Weightages were taken based on the correlation coefficients obtained. These weightages will be different for different parameters depending on the level of correlation obtained between the various parameters. Here the lead time is taken as the dependent variable and the other parameters as the independent variables. The correlation obtained between the lead time and the other parameters was taken as the basis for arriving at the weightages (***Table 1***). This is based on the concept put forward by Garde and Subramanian [14] ***Equation (2)***.

In this table, W_1, W_2, W_3, W_4, W_5, W_6, W_7, and W_8 are the weightages, which will be different for different counts and, hence, KPI values (***Table 1***).

Table 1. Correlation between the lead time and other parameters and weightages – 40 Ne (14.76 tex) carded yarn. ***Note:*** **Significant at 5% level; **Significant at 1% level.*

S. no.	Parameters	Pearson correlation coefficient	Weightages
1	Lead time (days) vs. machine utilisation	**– 0.606 ****	0.30
2	Lead time (days) vs. spindle production	**– 0.592 ****	0.25
3	Lead time (days) vs. end breaks / 100 spindle – hour	**0.545 ****	0.15
4	Lead time (days) vs. HOK	**0.530 ****	0.11
5	Lead time (days) vs. roving production	**– 0.450 ***	0.09
6	Lead time (days) vs. yarn realisation	**– 0.433 ***	0.05
7	Lead time (days) vs. CSP (count strength product)	**– 0.412 ***	0.03
8	Lead time (days) vs. UKG (units/kg of yarn)	**0.406 ***	0.02

$$\text{KPI for parameters [CSP, roving production, yarn realisation, spindle production, machine utilisation]} = \frac{\text{Observed Performance}}{\text{Standard Performance}} \times 100$$

$$\text{KPI for parameters [end breaks, UKG, HOK, lead time]} = \frac{\text{Standard Performance}}{\text{Observed Performance}} \times 100 \quad (1)$$

Equation (1).

$$\text{Overall KPI (40 Ne (14.76 tex) carded yarn)} = W_1 \times \text{KPI (machine utilisation)} + W_2 \times \text{KPI (spindle production)} + W_3 \times \text{KPI (end breaks)} + W_4 \times \text{KPI (HOK)} + W_5 \times \text{KPI (roving production)} + W_6 \times \text{KPI (yarn realisation)} + W_7 \times \text{KPI (CSP)} + W_8 \times \text{KPI (units/kg of yarn)} \quad (2)$$

Equation (2).

Results and discussion

Individual KPI

40 Ne (14.76 tex) carded yarn

Tables 2-4 show the KPI computed in respect of 40s carded counts taking into account the actual value and also the norm given by SITRA (South India Textile Research Association) for various parameters.

Overall KPI

40 Ne (14.76 tex) carded yarn

Table 5 gives the overall KPI computed by giving appropriate weightages.

Multiple linear regression analysis

In order to find out the dependence of the overall KPI on the following independent variables: machine utilisation, yarn

Table 2. Values of KPI computed for CSP, roving production & yarn realisation – 40 Ne (14.76 tex) carded yarn (KPI = OBS/STD × 100). ***Note:*** ** Norm.*

Mill No.	CSP *(2500)	KPI	Roving production, kg/spl/hr, *(4.05)	KPI	Yarn realisation, %, *(85)	KPI
1	2300	92	3	74.1	81	95.3
2	2500	100	2.7	66.7	83	97.6
3	2450	98	3.32	82	85	100
4	2450	98	3.3	81.5	85	100
5	2350	94	4.2	103.7	87	102.4
6	2400	96	3	74.1	85	100
7	2700	108	4.6	113.6	85	100
8	2200	88	3.85	95.1	88	103.5
9	2600	104	4.8	118.5	85.2	100.2
10	2300	92	1.95	48.1	84	98.8
11	2600	104	6.8	167.9	84	98.8
12	2320	92.8	4.62	114.1	86	101.2
13	2400	96	4.5	111.1	86	101.2
14	2600	104	3.5	86.4	87.13	102.5
15	2500	100	3.8	93.8	86	101.2
16	2450	98	3.93	97	84	98.8
17	2400	96	4.8	118.5	83	97.6
18	2300	92	1.8	44.4	80	94.1
19	2000	80	2.77	68.4	86.5	101.8
20	2200	88	2.8	69.1	87	102.4
21	2200	88	3	74.1	90	105.9
22	2200	88	1.85	45.7	82	96.5
23	2200	88	2.7	66.7	82	96.5
24	2200	88	2.7	66.7	80	94.1
25	2300	92	2.6	64.2	81	95.3
26	2500	100	5.83	144	85	100
27	2800	112	6	148.1	86	101.2
28	2400	96	4	98.8	80	94.1
29	2450	98	5	123.5	81	95.3
30	2400	96	5.44	134.3	90	105.9
31	2450	98	6.5	160.5	81	95.3

Table 3. Values of KPI computed for spindle production, machine utilisation – 40 Ne (14.76 tex) carded yarn (KPI = OBS/STD × 100). ***Note:*** ** Norm.*

Mill no.	Spindle production, gms/spl/shift, *(120)	KPI	Machine utilisation, %, *(98)	KPI
1	77	64.2	94	95.9
2	90	75	95	96.9
3	98	81.7	90	91.8
4	115	95.8	97	99
5	105	87.5	95	96.9
6	80	66.7	84	85.7
7	106	88.3	88	89.8
8	96	80	84	85.7
9	104	86.7	97	99
10	83	69.2	80	81.6
11	100	83.3	85	86.7
12	115	95.8	85	86.7
13	85	70.8	95	96.9
14	110	91.7	82	83.7
15	100	83.3	85	86.7
16	102	85	83	84.7
17	105	87.5	87	88.8
18	60	50	85	86.7
19	80	66.7	84	85.7
20	88	73.3	86	87.8
21	75	62.5	85	86.7
22	72	60	85	86.7
23	78	65	82	83.7
24	75	62.5	82	83.7
25	80	66.7	87	88.8
26	103	85.8	84	85.7
27	110	91.7	95	96.9
28	85	70.8	86	87.8
29	85	70.8	88	89.8
30	110	91.7	95	96.9
31	112	93.3	95	96.9

realisation, end breaks, CSP, HOK, roving production, spindle production and UKG, the multiple correlation coefficient was computed.

It is interesting to note that UKG has a strong effect on the overall KPI (***Table 6***).

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

$X_1 \rightarrow$ 29.9% increase $X_2 \rightarrow$ 25% increase
$X_3 \rightarrow$ 15% increase $X_4 \rightarrow$ 11% increase
$X_5 \rightarrow$ 9% increase $X_6 \rightarrow$ 5.2% increase
$X_7 \rightarrow$ 3% increase $X_8 \rightarrow$ 2% increase

Based on the facts above, a model of the multiple linear regression analysis for the dependent variable – overall KPI and independent variables (machine utilisation, yarn realisation, end breaks, CSP, HOK, roving production, spindle production and UKG) is proposed. The correlation between the lead time and other variables is strong.

Overall KPI (Y) = –0.084 + 0.299 (machine utilisation) + 0.250 (spindle production) + 0.150 (end breaks) + 0.110 (HOK) + 0.090 (roving production) + 0.052 (yarn realisation) + 0.030 (CSP) + 0.020 (UKG)

The Durbin–Watson test shows a value of more than 1, which indicates that all the variables are significant (machine utilisation, yarn realisation, end breaks, CSP, HOK, roving production, spindle production & UKG).

Figure 1 illustrates the overall KPI for various mills.

It is apparent that 6 mills (No. 7, 8, 12, 27, 30 & 31) producing 40 Ne (14.76 tex) carded yarn recorded a value of more than 100 in the overall KPI, which represents outstanding performance. Mill No. 22 shows a value of 61.2, which is the lowest recorded. The reasons for poor performance can be attributed to the poor KPI in a number of cases. The mill can find out the reason for the poor performance in order to bring the KPI to the level of the best mills. In addition to improving the performance of this mill, it is also important that a training program be organised to highlight the importance of the overall KPI. The performance of the overall KPI is given in ***Table 7***. The rating of the overall KPI will be on a subjective basis. The mills are judged as per the following scale.

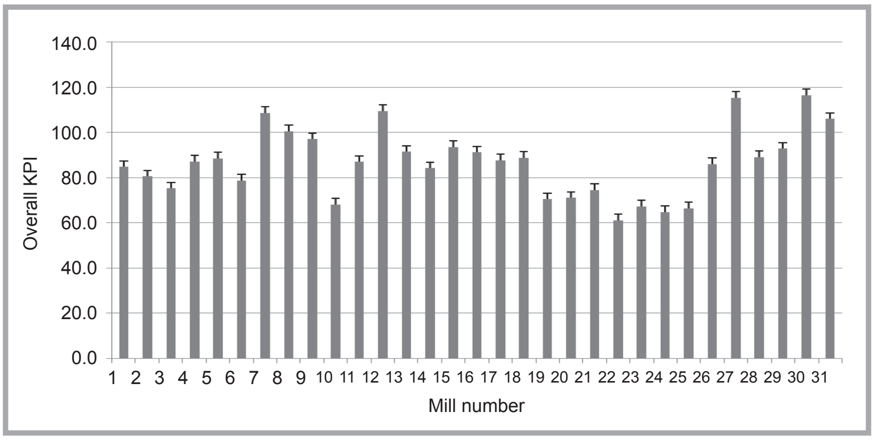


Figure 1. *Overall KPI for various mills – 40 Ne (14.76 tex) carded yarn.*

Table 8 gives the overall KPI and lead time (days) for 31 mills producing 40s carded count.

There exists a highly significant negative correlation between the two, which is obvious (***Table 9***).

Table 10 shows Fisher–Snedecor test for model significance.

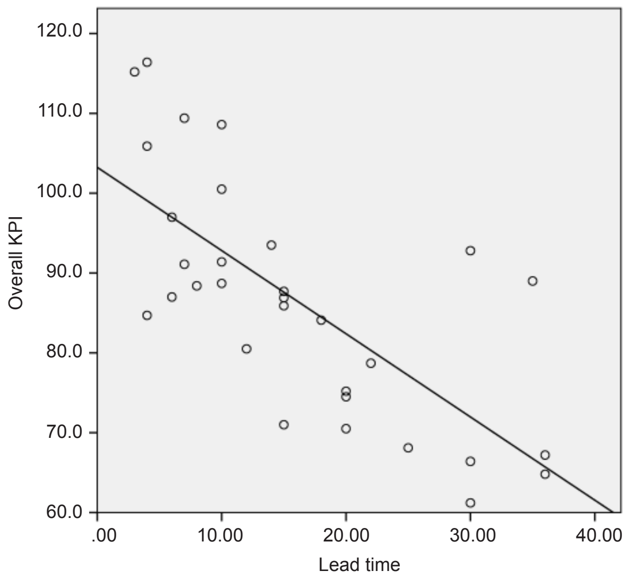
Figure 2 illustrates the relationship between the overall KPI and the lead time.

Table 4. *Values of KPI computed for end breaks/100 spindle-hr, UKG, HOK & ead time – 40 Ne (14.76 tex) carded yarn (KPI = STD/OBS × 100).* ***Note:*** ** Norm [25].*

Mill No.	End breaks/100 spindle-hr *(6.6)	KPI	UKG, units/kg of yarn *(4.72)	KPI	HOK *(8.65)	KPI	Lead time, days *(3)	KPI
1	6	110	2.9	162.8	16	54.1	4	75
2	12	55	3.6	131.1	12	72.1	12	25
3	16	41.3	2.9	162.8	38	22.8	20	15
4	9	73.3	2.9	162.8	25	34.6	6	50
5	8	82.5	3.75	125.9	18	48.1	8	37.5
6	7	94.3	3.1	152.3	21	41.2	22	13.6
7	3	220	3	157.3	19	45.5	10	30
8	3	220	3.2	147.5	39	22.2	10	30
9	6	110	3.1	152.3	13	66.5	6	50
10	12	55	2.7	174.8	38	22.8	25	12
11	15	44	4	118	12	72.1	15	20
12	3	220	3.1	152.3	18	48.1	7	42.9
13	5	132	3.4	138.8	23	37.6	10	30
14	8	82.5	2.8	168.6	22	39.3	18	16.7
15	5	132	3.08	153.2	13	66.5	14	21.4
16	5	132	2.9	162.8	20	43.3	7	42.9
17	7	94.3	2.9	162.8	28	30.9	15	20
18	3	220	2.9	162.8	38	22.8	10	30
19	15	44	3.7	127.6	18	48.1	20	15
20	24	27.5	3.2	147.5	18	48.1	15	20
21	12	55	4.52	104.4	12	72.1	20	15
22	26	25.4	4.05	116.5	38	22.8	30	10
23	14	47.1	3.5	134.9	36	24	36	8.3
24	17	38.8	3.8	124.2	40	21.6	36	8.3
25	22	30	4.49	105.1	30	28.8	30	10
26	8	82.5	4.3	109.8	30	28.8	15	20
27	3	220	4.5	104.9	15	57.7	3	100
28	5	132	4	118	15	57.7	35	8.6
29	4	165	4.5	104.9	38	22.8	30	10
30	3	220	2.96	159.5	12	72.1	4	75
31	5	132	3.2	147.5	11	78.6	4	75

Table 5. Overall KPI and individual KPIs for mills — 40 Ne (14.76 tex) carded yarn.

Mill No.	KPI								Overall KPI	Rating
	Machine utilisation	Spindle production	End breaks	HOK	Roving production	Yarn realisation	CSP	UKG		
1	95.9	64.2	110	54.1	74.1	95.3	92	162.8	84.7	Good
2	96.9	75	55	72.1	66.7	97.6	100	131.1	80.5	Good
3	91.8	81.7	41.3	22.8	82	100	98	162.8	75.2	Poor
4	99	95.8	73.3	34.6	81.5	100	98	162.8	87	Good
5	96.9	87.5	82.5	48.1	103.7	102.4	94	125.9	88.4	Good
6	85.7	66.7	94.3	41.2	74.1	100	96	152.3	78.7	Poor
7	89.8	88.3	220	45.5	113.6	100	108	157.3	108.6	Excellent
8	85.7	80	220	22.2	95.1	103.5	88	147.5	100.5	Excellent
9	99	86.7	110	66.5	118.5	100.2	104	152.3	97	Very good
10	81.6	69.2	55	22.8	48.1	98.8	92	174.8	68.1	Poor
11	86.7	83.3	44	72.1	167.9	98.8	104	118	86.9	Good
12	86.7	95.8	220	48.1	114.1	101.2	92.8	152.3	109.4	Excellent
13	96.9	70.8	132	37.6	111.1	101.2	96	138.8	91.4	Very good
14	83.7	91.7	82.5	39.3	86.4	102.5	104	168.6	84.1	Good
15	86.7	83.3	132	66.5	93.8	101.2	100	153.2	93.5	Very good
16	84.7	85	132	43.3	97	98.8	98	162.8	91.1	Very good
17	88.8	87.5	94.3	30.9	118.5	97.6	96	162.8	87.7	Good
18	86.7	50	220	22.8	44.4	94.1	92	162.8	88.7	Good
19	85.7	66.7	44	48.1	68.4	101.8	80	127.6	70.5	Poor
20	87.8	73.3	27.5	48.1	69.1	102.4	88	147.5	71	Poor
21	86.7	62.5	55	72.1	74.1	105.9	88	104.4	74.5	Poor
22	86.7	60	25.4	22.8	45.7	96.5	88	116.5	61.2	Poor
23	83.7	65	47.1	24	66.7	96.5	88	134.9	67.2	Poor
24	83.7	62.5	38.8	21.6	66.7	94.1	88	124.2	64.8	Poor
25	88.8	66.7	30	28.8	64.2	95.3	92	105.1	66.4	Poor
26	85.7	85.8	82.5	28.8	144	100	100	109.8	85.9	Good
27	96.9	91.7	220	57.7	148.1	101.2	112	104.9	115.2	Excellent
28	87.8	70.8	132	57.7	98.8	94.1	96	118	89	Good
29	89.8	70.8	165	22.8	123.5	95.3	98	104.9	92.8	Very good
30	96.9	91.7	220	72.1	134.3	105.9	96	159.5	116.4	Excellent
31	96.9	93.3	132	78.6	160.5	95.3	98	147.5	105.9	Excellent



Equations Y = a + bx	Value	t test significance "Yes" or "No"	Adj. R-square	F test significance "Yes" or "No"
Intercept	-1.042	Yes	.491	Yes
Slope	103.237	Yes		Yes

Figure 2. Relationship between overall KPI & lead time – 40 Ne (14.76 tex) carded yarn.

Conclusions

On the basis of the overall KPI, the result shows that only in a few mills, was an overall index of more than 100 achieved for all the counts. Thus, there is an urgent need to improve the performance of the mills taking into account the overall KPI. This index can be used as an effective management tool in the realm of supply chain management and is applicable to any count.

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Table 6. Regression analysis – overall KPI –40 Ne (14.76 tex) carded yarn. ***Note:*** *** p<0.01; * p<0.05.*

S. No.	Variables	Coefficient	SE	t	'p' value
	(Constant)	–.084			
1	Machine utilisation	.299	.001	260.325	<.001**
2	Spindle production	.250	.001	301.363	<.001**
3	End breaks	.150	.000	1634.981	<.001**
4	HOK	.110	.000	313.000	<.001**
5	Roving production	.090	.000	298.963	<.001**
6	Yarn realisation	.052	.002	27.340	<.001**
7	CSP	.030	.001	27.320	<.001**
8	UKG	.020	.000	66.049	<.001**
	R value	1.000			
	R^2 value	1.000			
	F value	1063536.91			
	Durbin-Watson test	2.106			

Table 7. Overall KPI rating – 40 Ne (14.76 tex) carded yarn.

Overall KPI	Rating
More than 100	Excellent
90 to 100	Very good
80 to 90	Good
Below 80	Poor

Table 10. Fisher–Snedecor test for model significance.

Fisher – Snedecor test for model significance
Computed F statistics = 29.891
Probability value (p = <.001)
Conclusion: The model is significant.

Table 9. Correlation analysis – 40 Ne (14.76 tex) carded yarn. ***Note:*** ** Significant at 1% level.*

S. No.	Variables	'r' value	'p' value
1	Lead time	-0.712	0.000*
2	Overall KPI		

Table 8. Overall KPI & lead time – 40 Ne (14.76 tex) carded yarn.

Mill No.	Overall KPI	Lead time, days
1	84.7	4
2	80.5	12
3	75.2	20
4	87	6
5	88.4	8
6	78.7	22
7	108.6	10
8	100.5	10
9	97	6
10	68.1	25
11	86.9	15
12	109.4	7
13	91.4	10
14	84.1	18
15	93.5	14
16	91.1	7
17	87.7	15
18	88.7	10
19	70.5	20
20	71	15
21	74.5	20
22	61.2	30
23	67.2	36
24	64.8	36
25	66.4	30
26	85.9	15
27	115.2	3
28	89	35
29	92.8	30
30	116.4	4
31	105.9	4

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