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Draw Frame Parameters Selection for Rotor Spinning Knitted Fabrics Using Multi-Criteria Decision Making Approach

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Abstract: Selecting optimum draw frame processing condition according to the mechanical and quality characteristics of the final yarn is an intricate aspect and is inherently a multi-criteria decision-making (MCDM) problem. Statistical methods have been used for solving such kind of problems but these methods are not able to consider the preferences of the producers and consumers about yarn properties to get an end product with defined characteristics. In the present work, the best draw frame parameters for 30Ne rotor spun yarn intended to be used for weft knitted fabric were selected by technique for order preference by similarity to ideal solutions (TOPSIS) approach. Three variables that are distance between back and middle rolls, delivery speed and break draft were considered and their performances were evaluated on the basis of seven quality parameters of the forty eight produced rotor yarns. The final ranking of the parameters was elicited in accordance with the relative closeness coefficient to the ideal solution and the best alternative which is able to increase weft knitting machine efficiency was presented. Consequently, stability of the proposed final ranking was verified after sensitivity analysis.

Key words: Decision-making · TOPSIS approach · Draw frame · Break draft · Rotor spun yarn · Weft knitted fabric

INTRODUCTION

Knitability of a yarn that affects circular weft knitting machine efficiency is known as knitting performance of a structure for a given yarn and is of major interest to the researchers. There are three main groups of the effective parameters on the knitability that are factors affecting the running of the yarn from package to the feeder, parameters affecting knitting machine condition and fabric properties and consequently yarn faults. Yarn properties specially, mechanical properties, friction characteristics, bending behavior, elasticity, unevenness and imperfections are the most important factors in these groups [1].

In return, properties of a yarn are affected by characteristics of the fibers, spinning preparation processes, setting done on machines and machine parts selection. A survey of the literature will reveal that there has been a great deal of research done on the roller drafting of staple fiber assemblies such as sliver due to the effect of drafting quality at the draw frame on fibers arrangement, fibers parallelization and fibers distribution [2]. The effect of the variables may transmit up to the fibrous assemble in yarn, affecting its structure and properties. Drafting quality is governed by processing variables such as break draft, roller setting, delivery speed and pressure on top-roller. Besides, there is a high degree of interaction between the different processing variables [3-5]. Therefore, optimum draw frame processing conditions selection among possible alternatives is a difficult task and a multi-criteria decision making problem. Since better results about the desired end-product properties will be obtained if the priorities and preferences of the decision-maker, namely the yarn producer is taken into consideration therefore multi-criteria decision-making methods are useful means for carrying out such an analysis [6].

The Technique for Order Preference by Similarity Ideal Solution Methodology (TOPSIS): Multi- criteria decision-making is a branch of Operations Research (OR), which deals with selection problems under the presence of a finite number of decision criteria and alternative. MCDM methods are still popularly used in the engineering problems. The weighted sum model (WSM), weighted product model (WPM), the analytic hierarchy process

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(AHP) and technique for order preference by similarity to ideal solutions (TOPSIS) are some widely used methods of MCDM and it is almost impossible to decide which one is the best method [7]. Multi-criteria decision making may be considered as a complex and dynamic process including one managerial level and one engineering level. A MCDM problem can be concisely expressed in matrix format (decision matrix).

$$\begin{array}{ccccc} & C_1 & C_2 & \cdots & C_n \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ A_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{array}$$

Where $A_1, A_2, .. A_m$ are possible alternatives among which decision makers have to choose, $C_1, C_2, \ldots, C_n$ are criteria with which alternative performance are measured, x_{ij} is the rating of alternative Ai with respect to the criterion C_j [8]. TOPSIS one of known classical MCDM method, was first developed by Hwang and Yoon (1981) for solving a MCDM problem. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [8, 9]. In recent years, TOPSIS has been successfully adopted in various fields, location analysis, construction processes, management and quality control [10]. There are some applications of MCDM methods in textile problems. The technological value of cotton fibers is determined by a hybrid method of MCDM [7]. Kaplan, Araz and Goktepe (2006) applied ELECTRE outranking method for the selection of rotor navel [6]. MCDM method was used to select cotton fibers and laydown in blow room [11]. This method was applied for selecting machine parts and appropriate setting in rotor spinning system [12, 13].

However there is not published literature that focuses on optimum spinning processing conditions using these methods. Therefore, in this study, assistance in reaching acceptable solution in order to select the appropriate setting in draw frame (passage No. 1) for 30Ne rotor yarn intended to be used for weft knitted fabric will be provided by TOPSIS approach. The procedure of TOPSIS can be expressed in a series of steps [8].

- Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as:

$$r_{ij} = f_{ij} / \sqrt{\sum_{j=1}^{J} f_{ij}^{2}}, j = 1,\ldots,J \quad i = 1,\ldots n \tag{1}$$

- Calculate the weighted normalized decision matrix. The weighted normalized value υ_{ij} is calculated as:

$$\upsilon_{ij} = \omega_i r_{ij}, \quad j = 1,\ldots,J \quad i = 1,\ldots n, \tag{2}$$

Where ω_i is the weight of the ith attribute or criterion and $\sum_{i=1}^{n} \omega_i = 1$

- Determine the positive ideal and negative ideal solution

$$A^+ = \{\upsilon_1^+, \ldots, \upsilon_n^+\} = \{(\max_j \upsilon_{ij} | i \in I), (\min_j \upsilon_{ij} | i \in J)\} \tag{3}$$

$$A^- = \{\upsilon_1^-, \ldots, \upsilon_n^-\} = \{(\min_j \upsilon_{ij} | i \in I), (\max_j \upsilon_{ij} | i \in J)\} \tag{4}$$

Where I is associated with benefit criteria and J is associated with cost criteria.

- Calculate the separation measure using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$D^+_j = \sqrt{\sum_{i=1}^{n} (\upsilon_{ij} - \upsilon_i^+)^2} \quad j = 1,\ldots,J. \tag{5}$$

$$D^-_j = \sqrt{\sum_{i=1}^{n} (\upsilon_{ij} - \upsilon_i^-)^2} \quad j = 1,\ldots,J \tag{6}$$

- Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_j with respect to A^+ is defined as

$$CC^*_j = D_j^- / (D_j^+ + D_j^-), \quad j = 1,\ldots,J. \tag{7}$$

Since $D_j^- \geq 0$ and $D_j^+ \geq 0$, then clearly $CC^*_j \in [0,1]$

- Ranking the preference order.

MATERIALS AND METHODS

Cotton fibers with 27 mm mean fiber length, 3.6 micronair fineness and 0.85 fiber maturity index, were furnished as a second draw frame sliver with linear density of 5.2 ktex. The 30 Ne yarn was spun on a Rieter RU04 rotor spinning machine with 900 tpm. The opening roller was designed for cotton fibers at the speed of 8200 t. min^{-1}. The 35 mm diameter rotor worked at a speed of 75000 t min^{-1}.

Table 1: Specifications of cotton rotor yarn samples

	Variables				Variables				Variables		
Alternative	DBBMR	DS	BD	Alternative	DBBMR	DS	BD	Alternative	DBBMR	DS	BD
A1	8	750	1.7	A17	10	550	1.41	A33	10	750	1.7
A2	14	750	1.41	A18	10	750	1.14	A34	8	550	1.41
A3	14	550	1.41	A19	12	650	1.7	A35	8	650	1.14
A4	14	550	1.7	A20	10	650	1.14	A36	10	550	1.7
A5	12	550	1.7	A21	8	550	1.7	A37	12	750	1.7
A6	8	700	1.7	A22	10	700	1.41	A38	14	650	1.41
A7	12	650	1.14	A23	8	700	1.41	A39	14	650	1.7
A8	8	650	1.7	A24	10	700	1.7	A40	10	650	1.7
A9	12	700	1.41	A25	14	750	1.14	A41	12	650	1.41
A10	10	700	1.14	A26	8	700	1.14	A42	14	700	1.41
A11	12	750	1.41	A27	14	700	1.41	A43	14	700	1.14
A12	14	750	1.7	A28	8	650	1.41	A44	10	650	1.41
A13	10	750	1.41	A29	14	550	1.14	A45	8	550	1.14
A14	12	750	1.14	A30	14	650	1.14	A46	10	550	1.14
A15	12	700	1.7	A31	12	550	1.14	A47	12	550	1.41
A16	8	750	1.41	A32	12	700	1.14	A48	10	550	1.14

DBBMR: Distance between back and middle rolls (mm) DS: delivery speed (m/min) BD: break draft

There were three main parameters in draw frame (passage No.1). These included delivery speed of 550, 650, 700 and 750 m/min, distance between back and middle rolls of 8, 10, 12 and 14 mm and break draft of 1.14, 1.41 and 1.70. Forty eight different yarn samples (all possible combinations) were produced according to the mentioned variables and specifications as shown in Table 1.

Load-elongation characteristics of the yarns were examined with Uster Tesorapid3. A test specimen of 500 mm was elongated at an extension rate of 500 mm/min. The unevenness and imperfections of 5 yarn samples for each group were measured with the Uster Tester 4 with a test speed of 400 m/min for 2.5 min. The hairiness of the yarns was measured with Premier Tester 7000. In the test, 10 samples with 100 m length were examined.

RESULTS AND DISCUSSION

The results of the experiments are shown in Table 2. A one-way ANOVA test was applied to determine the effects of considered parameters on yarn quality parameters.

Average values of the yarn quality parameters (Table2) were compared at 5% significance level and grouped according to the Duncan Multiple Range Test. Results of the Univariate analysis are summarized in Tables 3 but Duncan Multiple Range Test results can not be shown due to space limitation. Statistical analysis showed that, main effect and interactive effect of the three variables on yarn properties are meaningful.

Importance of the Yarn Quality Parameters for Knitability: As mentioned knitability is known as knitting performance of a structure for a given yarn, affects knitting machine efficiency and is of major interest to the researchers. Studies showed that, the tension of a yarn running into a large diameter circular knitting machine is an important technological parameter that affects knitting machine failure and yarn breakage [14-17]. Therefore, higher tenacity and elongation at break of the yarn and lower friction between yarn and machine surfaces such as needle is useful to reduce yarn breakage.

However, mechanical properties of a yarn are a function of yarn imperfections and unevenness. The more the imperfections and unevenness are, the more yarn breakages occur due to improper and concentrated distribution of the twist. Therefore, knitability results correlated with yarn irregularity and the numbers of thick and thin places [18].

Hairiness is another factor that affects friction between needle and yarn. Friction between yarn and machine surfaces and the yarn bending rigidity is related to yarn surface properties such as wrapping fibers and hairiness. Increase in hairiness and wrapper fibers, produces more friction between the yarn and metal surface and increase yarn bending flexural rigidity. Increase in friction leads to an increase in yarn tension and breakage [14-17].

Performing TOPSIS Approach: In the first step of the TOPSIS algorithm if a ranking between these properties is needed the most important one to increase machine

Table 2: Quality parameters of the yarns (Performance values of the alternatives or decision matrix)

Alternative	Tenacity (cN/tex) X_6^+	Elongation (%) X_7^+	(CV %) X_1^-	Thin places (-50%) X_2^-	Thick places (+50%) X_3^-	Neps (+280%) X_4^-	Hairiness (H) X_5^-
A1	15.06	6.8	14.56	25.2	62.4	31.2	6.54
A2	14.9	6.68	14.65	28.8	56	35.8	5.19
A3	13	6.24	15.13	41.8	81.2	49.4	5.79
A4	15.25	6.72	14.78	37.2	43.8	19.6	6.48
A5	14.7	6.67	14.65	25.2	54.2	24.2	4.99
A6	14.28	6.72	14.38	28.2	46.8	23	5.09
A7	13.42	6.44	14.93	41.4	70.2	33.4	5.62
A8	14.1	6.74	14.68	35.8	35.8	31.8	5.33
A9	12.63	6.27	15.1	38.2	38.2	49.2	5.13
A10	13	6.76	14.58	30.2	30.20***	27.4	5.75
A11	12.89	6.42	14.73	34.4	63.8	31.6	5.25
A12	14.02	6.71	15.01	34.8	53.2	34	6.41
A13	13.36	6.18	14.68	32.6	63.2	30.8	5.7
A14	14.8	6.45	14.92	51.6	72.2	38.2	5.75
A15	14.22	6.44	14.71	29.4	59.6	25.2	5.73
A16	14.64	6.37	14.21***	20.8	40.6	22.4	5.58
A17	13.99	6.14	15.09	34.4	82.2	65.6	5.68
A18	15.2	6.65	14.48	16.20***	50.4	29	5.39
A19	13.85	6.38	14.66	36.4	60.4	33.2	5.71
A20	13.85	6.41	14.35	23.2	46.6	28.8	5.4
A21	13.98	6.36	14.7	30.8	64.2	34.8	5.12
A22	15.21	6.56	14.24	26.2	48.2	26.8	6.58
A23	14.25	6.46	15.18	40.2	94.4	71.8	5.74
A24	14.7	6.53	14.66	26.2	56.2	30.4	5.2
A25	14.98	6.63	14.94	36.4	66.2	35.8	5.35
A26	15.39	6.73	14.85	34.8	71.6	49.6	6.63
A27	14.54	6.42	14.54	25.4	53.6	21.6	6.55
A28	14.59	6.32	14.51	35	50	28.6	4.94***
A29	12.77	6.79	14.57	28	73.5	36	5.21
A30	15.46***	6.83	15.05	35.5	92	71	6.59
A31	13.97	6.47	15.1	45.5	75	39.5	5.17
A32	13.62	6.48	15.3	43.5	82	26	6.56
A33	13.34	6.51	14.92	38.5	67.5	28.5	6.55
A34	14.05	6.72	14.78	26.5	73.5	31.5	5.61
A35	14.58	6.78	15.61	34.5	57	33	5.21
A36	14.11	6.61	14.7	32.5	60	34	5.1
A37	14.46	6.86***	15.11	43.5	74.5	49	5.3
A38	13.38	6.43	14.65	33	60	30.9	5.22
A39	13.33	6.47	15.31	55	98.5	64.5	5.44
A40	14.65	6.43	14.71	42	75	39.5	6.52
A41	15.13	6.64	14.81	30	71.16	26	5.3
A42	13.22	6.47	14.97	34.5	73	46	5.2
A43	12.85	6.6	14.74	32.5	64.5	36	5.18
A44	13.96	6.53	14.58	24	56	27	5.12
A45	14.07	6.55	14.42	19	51.5	19.50***	5.51
A46	14.98	6.72	14.45	24.5	59	31	5.37
A47	14.13	6.4	14.47	24.5	54.5	28.5	5.66
A48	13.23	6.37	14.45	22.5	50.5	23.5	5.73

*** Shows the best value for the criterion (minimum or maximum according to the property)

Table 3: Results of the statistical analysis to show the effect of the factors on samples properties

	Tenacity (X_6)				Elongation (X_7)			
Property	Sum of Squares	M.S	F	Sig.	Sum of Squares	M.S	F	Sig.
Corrected Model	270.142[a]	6.282	16.137	0	14.067[a]	0.327	0.866	0.713
Intercept	89346.103	89346.103	2.30E+05	0	19280.11	19280.11	5.10E+04	0
DBBMR	27.38	9.127	23.444	0	0.635	0.212	0.56	0.642
DS	9.696	3.232	8.302	0	0.376	0.125	0.332	0.802
BD	0.687	0.344	0.883	0.414	1.95	0.975	2.581	0.077
DBBMR*PS	30.18	3.353	8.614	0	2.393	0.266	0.704	0.706
DBBMR*BD	26.845	4.474	11.493	0	0.801	0.133	0.353	0.908
DS*BD	32.59	5.432	13.952	0	1.727	0.288	0.762	0.6
DBBMR*DS*BD	163.624	11.687	30.021	0	5.297	0.378	1.001	0.451
Error	169.347	0.389			164.737	0.378		
Total	96073.731				20720.815			
Corrected Total	439.489				178.804			
a. R Squared = .615 (Adjusted R Squared = .577)					a. R Squared = .079 (Adjusted R Squared = -.012)			
Property	Unevenness (X_1)				Thin places (X_2)			
Corrected Model	20.043[a]	0.445	3.728	0	15226.474[a]	338.366	3.689	0
Intercept	50209.249	50209.249	4.20E+05	0	246795.072	246795.072	2.69E+03	0
DBBMR	2.612	0.871	7.287	0	2760.09	920.03	10.031	0
DS	0.262	0.087	0.731	0.535	721.465	240.488	2.622	0.052
BD	0.245	0.122	1.024	0.361	376.613	188.307	2.053	0.131
DBBMR*PS	3.32	0.369	3.087	0.002	2835.579	315.064	3.435	0.001
DBBMR*BD	2.542	0.424	3.546	0.002	3740.514	623.419	6.797	0
DS*BD	3.287	0.548	4.585	0	1889.951	314.992	3.434	0.003
DBBMR*DS*BD	6.684	0.418	3.497	0	2494.442	155.903	1.7	0.049
Error	23.18	0.119			17794.225	91.723		
Total	52372.154				289879.25			
Corrected Total	43.222				33020.699			
a. R Squared = .464 (Adjusted R Squared = .339)					a. R Squared = .461 (Adjusted R Squared = .336)			
Property	Thick places (X_3)				Hairiness (X_5)			
Corrected Model	50890.086[a]	1130.891	7.096	0	23.980[a]	0.533	13.712	0
Intercept	883404.073	883404.073	5.54E+03	0	2918.459	2918.459	7.51E+04	0
DBBMR	3859.486	1286.495	8.072	0	0.555	0.185	4.763	0.005
DS	1254.806	418.269	2.625	0.052	1.302	0.434	11.166	0
BD	258.392	129.196	0.811	0.446	0.48	0.24	6.17	0.004
DBBMR*PS	14366.28	1596.253	10.016	0	3.671	0.408	10.495	0
DBBMR*BD	11059.018	1843.17	11.565	0	1.95	0.325	8.363	0
DS*BD	4988.975	831.496	5.217	0	5.923	0.987	25.398	0
DBBMR*DS*BD	16101.999	1006.375	6.315	0	9.938	0.621	15.982	0
Error	30917.837	159.37			1.943	0.039		
Total	1009371.89				3068.826			
Corrected Total	81807.923				25.924			
a. R Squared = .622 (Adjusted R Squared = .534)					a. R Squared = .925 (Adjusted R Squared = .858)			

efficiency and reduce yarn breakage during knitting process is assumed to be yarn hairiness followed by unevenness, thick places, neps, thin places, tenacity and elongation.

In this study tenacity and elongation are shown by positive sign. It means that higher value of the property is better to raise knitability. Also, hairiness, coefficient of mass variation (CV%) and imperfections are shown by negative sign in the investigation. The alternatives were evaluated on the basis of these quality parameters which are the criteria of the TOPSIS.

The weights of these criteria which are necessary inputs for TOPSIS application were determined according to their importance level for knitability and end breakage. Five of the criteria (CV%, thin places, thick places, nep and hairiness were required to be minimized and others (tenacity, elongation) to be maximized.

Table 4: Intensity of the effect of yarn properties on knitting machine efficiency (from one to ten)

Company	Tenacity	Elongation	Hairiness	Unevenness	Thick places	Thin places	Neps
A	5	3	10	8	10	5	7
B	5	5	10	10	10	5	10
C	3	4	10	10	10	3	10
D	5	5	10	10	10	5	10
E	5	5	10	10	10	5	10
F	2	1	10	10	10	5	10
G	5	5	10	10	10	5	10
H	7	3	9	10	8	4	7

Table 5: The normalized decision matrix

Alternative	Tenacity (cN/tex) X_6^+	Elongation (%) X_7^+	(CV %) X_1^-	Thin places (-50%) X_2^-	Thick places (+50%) X_3^-	Neps (+280%) X_4^-	Hairiness (H) X_5^-
A1	0.15071	0.150145	0.142373	0.107984	0.140978	0.120966	0.167003
A2	0.14912	0.146705	0.143214	0.12341	0.126519	0.138801	0.13253
A3	0.13003	0.137598	0.147885	0.179117	0.183452	0.19153	0.147851
A4	0.15254	0.147499	0.144524	0.159405	0.098956	0.075992	0.165471
A5	0.14703	0.147279	0.143214	0.107984	0.122452	0.093826	0.127423
A6	0.14283	0.149947	0.140536	0.120839	0.105733	0.089174	0.129976
A7	0.13432	0.142229	0.14595	0.177403	0.1586	0.129496	0.14351
A8	0.14108	0.147213	0.143527	0.153406	0.080881	0.123292	0.136105
A9	0.12633	0.138326	0.14767	0.16369	0.086304	0.190754	0.130998
A10	0.13003	0.147742	0.142569	0.12941	0.06823	0.106233	0.14683
A11	0.12893	0.141567	0.143957	0.147407	0.144141	0.122517	0.134062
A12	0.14029	0.147962	0.146693	0.149121	0.120193	0.131822	0.163683
A13	0.13363	0.136099	0.143468	0.139694	0.142785	0.119415	0.145553
A14	0.14808	0.138591	0.145872	0.22111	0.163119	0.148106	0.14683
A15	0.14232	0.140068	0.143781	0.125982	0.134652	0.097703	0.146319
A16	0.14647	0.142494	0.138914	0.08913	0.091726	0.086847	0.142489
A17	0.13993	0.138502	0.147534	0.147407	0.185711	0.254339	0.145042
A18	0.15203	0.146198	0.141553	0.069418	0.113867	0.112436	0.137637
A19	0.13853	0.141126	0.143273	0.155977	0.136459	0.12872	0.145808
A20	0.13858	0.141457	0.140302	0.099414	0.105281	0.111661	0.137892
A21	0.1399	0.140906	0.143683	0.131981	0.145044	0.134924	0.130742
A22	0.15218	0.144655	0.139227	0.112269	0.108896	0.103907	0.168024
A23	0.14253	0.139583	0.148355	0.17226	0.213274	0.278377	0.146574
A24	0.1471	0.143993	0.143351	0.112269	0.12697	0.117864	0.132785
A25	0.14983	0.145404	0.146087	0.155977	0.149563	0.138801	0.136615
A26	0.15402	0.148403	0.145149	0.149121	0.161763	0.192305	0.169301
A27	0.14543	0.141567	0.142139	0.108841	0.121096	0.083746	0.167258
A28	0.14594	0.141788	0.141807	0.149978	0.112963	0.110886	0.126146
A29	0.12777	0.147279	0.142413	0.119982	0.166056	0.139576	0.13304
A30	0.15463	0.15063	0.147143	0.152121	0.207852	0.275275	0.16828
A31	0.13973	0.146639	0.147612	0.194971	0.169444	0.153146	0.132019
A32	0.13623	0.143486	0.149566	0.186401	0.185259	0.100805	0.167513
A33	0.13344	0.145272	0.145814	0.164976	0.1525	0.110498	0.167258
A34	0.14053	0.148183	0.144465	0.113555	0.166056	0.122129	0.143255
A35	0.14583	0.149506	0.152596	0.147835	0.128778	0.127945	0.13304
A36	0.14114	0.145779	0.143742	0.139265	0.135556	0.131822	0.130232
A37	0.14463	0.148403	0.14769	0.186401	0.168315	0.189979	0.135339
A38	0.13392	0.141788	0.143175	0.141408	0.135556	0.119803	0.133296
A39	0.13333	0.143552	0.149645	0.23568	0.222537	0.250074	0.138914
A40	0.14653	0.141788	0.14382	0.179974	0.169444	0.153146	0.166492
A41	0.15133	0.149131	0.144778	0.128553	0.160769	0.100805	0.135339
A42	0.13223	0.142824	0.146302	0.147835	0.164926	0.178347	0.132785
A43	0.12853	0.145757	0.144133	0.139265	0.145722	0.139576	0.132274
A44	0.13963	0.146198	0.14251	0.102842	0.126519	0.104682	0.130742
A45	0.14073	0.144875	0.140966	0.081417	0.116352	0.075604	0.140701
A46	0.14983	0.148183	0.14122	0.104985	0.133296	0.120191	0.137126
A47	0.14133	0.141126	0.141435	0.104985	0.12313	0.110498	0.144531
A48	0.13233	0.140465	0.14122	0.096414	0.114093	0.091112	0.146319

Table 6: Importance of the criteria and vector of corresponding weight of each criterion

Criteria	Relative importance (RI_j)	Weight of each criterion $RI_j / \sum_{j=1}^{j=n} RI_j$
Tenacity (cN/tex)	7.375	0.085
Elongation (%)	3.875	0.0752
CV (%)	9.75	0.1893
Thin (-50%)	4.625	0.0898
Thick (+50%)	9.75	0.1893
Nep (+280%)	9.25	0.1796
Hairiness (H)	9.875	0.1917

Table 7: the Weighted Normalized Decision Matrix

			Yarn evenness and imperfections				
Sample	Tenacity (cN/tex) X_6^+	Elongation (%) X_7^+	(CV %) X_1^-	Thin places (-50%) X_2^-	Thick places (+50%) X_3^-	Neps (+280%) X_4^-	Hairiness (H value) X_5^-
1	0.0128	0.0113	0.02695	0.0097	0.02669	0.02173	0.03202
2	0.01267	0.01104	0.02711	0.01108	0.02395	0.02493	0.02541
3	0.01105	0.01035	0.028	0.01609	0.03473	0.0344	0.02835
4	0.01296	0.0111	0.02736	0.01432	0.01873	0.01365	0.03173
5	0.01249	0.01108	0.02711	0.0097	0.02318	0.01685	0.02443
6	0.01213	0.01128	0.02661	0.01085	0.02002	0.01602	0.02492
7	0.01141	0.0107	0.02763	0.01593	0.03003	0.02326	0.02752
8	0.01199	0.01108	0.02717	0.01378	0.01531	0.02214	0.0261
9	0.01073	0.01041	0.02796	0.0147	0.01634	0.03426	0.02512
10	0.01105	0.01112	0.02699	0.01162	0.01292	0.01908	0.02815
11	0.01095	0.01065	0.02725	0.01324	0.02729	0.02201	0.02571
12	0.01192	0.01113	0.02777	0.01339	0.02275	0.02368	0.03139
13	0.01135	0.01024	0.02716	0.01255	0.02703	0.02145	0.02791
14	0.01258	0.01043	0.02762	0.01986	0.03088	0.0266	0.02815
15	0.01209	0.01054	0.02722	0.01131	0.02549	0.01755	0.02806
16	0.01244	0.01072	0.0263	0.008	0.01737	0.0156	0.02732
17	0.01189	0.01042	0.02793	0.01324	0.03516	0.04568	0.02781
18	0.01292	0.011	0.0268	0.00623	0.02156	0.02019	0.02639
19	0.01177	0.01062	0.02712	0.01401	0.02583	0.02312	0.02796
20	0.01177	0.01064	0.02656	0.00893	0.01993	0.02006	0.02644
21	0.01188	0.0106	0.0272	0.01185	0.02746	0.02423	0.02507
22	0.01293	0.01088	0.02636	0.01008	0.02062	0.01866	0.03222
23	0.01211	0.0105	0.02809	0.01547	0.04038	0.05	0.02811
24	0.0125	0.01083	0.02714	0.01008	0.02404	0.02117	0.02546
25	0.01273	0.01094	0.02766	0.01401	0.02832	0.02493	0.0262
26	0.01308	0.01117	0.02748	0.01339	0.03062	0.03454	0.03246
27	0.01235	0.01065	0.02691	0.00978	0.02293	0.01504	0.03207
28	0.0124	0.01067	0.02685	0.01347	0.02139	0.01992	0.02419
29	0.01085	0.01108	0.02696	0.01078	0.03144	0.02507	0.02551
30	0.01314	0.01133	0.02786	0.01366	0.03935	0.04944	0.03227
31	0.01187	0.01103	0.02795	0.01751	0.03208	0.02751	0.02531
32	0.01157	0.0108	0.02832	0.01674	0.03507	0.01811	0.03212
33	0.01134	0.01093	0.02761	0.01482	0.02887	0.01985	0.03207
34	0.01194	0.01115	0.02735	0.0102	0.03144	0.02194	0.02747
35	0.01239	0.01125	0.02889	0.01328	0.02438	0.02298	0.02551
36	0.01199	0.01097	0.02721	0.01251	0.02566	0.02368	0.02497
37	0.01229	0.01117	0.02796	0.01674	0.03187	0.03412	0.02595
38	0.01138	0.01067	0.02711	0.0127	0.02566	0.02152	0.02556
39	0.01133	0.0108	0.02833	0.02117	0.04213	0.04492	0.02664
40	0.01245	0.01067	0.02723	0.01616	0.03208	0.02751	0.03192
41	0.01286	0.01122	0.02741	0.01155	0.03044	0.01811	0.02595
42	0.01123	0.01075	0.0277	0.01328	0.03122	0.03203	0.02546
43	0.01092	0.01097	0.02729	0.01251	0.02759	0.02507	0.02536
44	0.01186	0.011	0.02698	0.00924	0.02395	0.0188	0.02507
45	0.01196	0.0109	0.02669	0.00731	0.02203	0.01358	0.02698
46	0.01273	0.01115	0.02674	0.00943	0.02524	0.02159	0.02629
47	0.01201	0.01062	0.02678	0.00943	0.02331	0.01985	0.02771
48	0.01124	0.01057	0.02674	0.00866	0.0216	0.01636	0.02806

Table 8: Values of Positive and Negative Ideal Solution

	CV%	Thin places	Thick places	neps	hairiness	Tenacity	Elongation
Ideal solution	X_1^-	X_2^-	X_3^-	X_4-	X_5^-	X_6^+	X_7^+
	0.0263	0.00623	0.01292	0.01358	0.02419	0.01314	0.01133
	0.02889	0.02117	0.04213	0.05	0.03246	0.01073	0.01024

Table 9: Distance of each alternative from the positive and negative ideal solution

Alternative	Distance from positive ideal(D^+)	Distance from negative ideal(D^-)	Alternative	Distance from positive ideal	Distance from negative ideal
A1	0.02	0.034	A25	0.022	0.03
A2	0.018	0.033	A26	0.031	0.021
A3	0.033	0.018	A27	0.016	0.042
A4	0.015	0.044	A28	0.015	0.038
A5	0.014	0.041	A29	0.024	0.03
A6	0.012	0.043	A30	0.047	0.009
A7	0.024	0.03	A31	0.028	0.026
A8	0.015	0.04	A32	0.028	0.033
A9	0.025	0.032	A33	0.023	0.034
A10	0.013	0.044	A34	0.023	0.032
A11	0.021	0.033	A35	0.019	0.034
A12	0.019	0.034	A36	0.019	0.033
A13	0.02	0.034	A37	0.031	0.021
A14	0.028	0.026	A38	0.019	0.035
A15	0.017	0.038	A39	0.046	0.008
A16	0.01	0.045	A40	0.028	0.025
A17	0.041	0.012	A41	0.02	0.036
A18	0.014	0.04	A42	0.029	0.024
A19	0.02	0.033	A43	0.022	0.031
A20	0.013	0.04	A44	0.015	0.039
A21	0.021	0.032	A45	0.013	0.044
A22	0.015	0.04	A46	0.017	0.036
A23	0.048	0.008	A47	0.016	0.038
A24	0.016	0.037	A48	0.014	0.042

Table 10: Relative closeness coefficient of each alternative to the ideal solution

Alternative	Relative closeness coefficient(CC_j)	Alternative	Relative closeness coefficient (CC_j)
A1	0.635	A25	0.577
A2	0.645	A26	0.408
A3	0.356	A27	0.726
\A4	0.749	A28	0.716
A5	0.745	A29	0.552
A6	0.777	A30	0.155
A7	0.557	A31	0.484
A8	0.732	A32	0.543
A9	0.562	A33	0.596
A10	0.773	A34	0.588
A11	0.619	A35	0.647
A12	0.634	A36	0.63
A13	0.628	A37	0.398
A14	0.49	A38	0.648
A15	0.692	A39	0.144
A16	0.815	A40	0.474
A17	0.233	A41	0.637
A18	0.746	A42	0.452
A19	0.617	A43	0.585
A20	0.747	A44	0.717
A21	0.606	A45	0.774
A22	0.727	A46	0.676
A23	0.137	A47	0.708
A24	0.692	A48	0.75

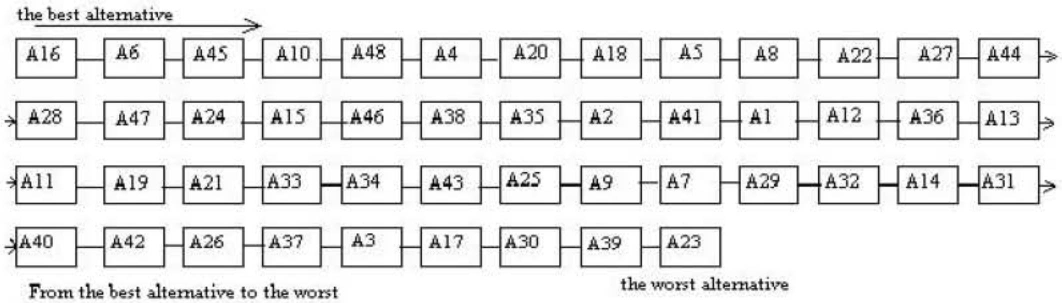

Fig. 1: Ranking the preference order (descending) of all alternatives

The determination of the weight requires the input of expert opinion. The weight of criteria can be determined after holding a meeting of the decision makers and discussing the criteria until a consensus is reached. Relative importance of the effective factors on machine efficiency was picked up based on the expert opinions that were proficient in weft knitting industry. Table 4 shows results of the discussion about importance of the rotor yarn properties.

As indicated above the first step in decision making using TOPSIS approach is identification of decision matrix. The performance values of the alternatives or decision matrix that is obtained from average values of yarn quality parameters has been shown in Table 2. At the next step normalized decision matrix was calculated using Table 2 and equation 1. Normalized decision matrix has been shown in Table 5.

Importance of the criteria was determined by using experts' ideas. In this case importance of the criterion was considered based on the effect of that criterion on weft knitting machine efficiency (knitability of the yarn). Table 6 shows relative importance of each criteria and weight vector. Relative importance of the criteria was considered from one to ten.

Considering the different importance of each criterion and calculating vector of the criteria, the weighted normalized decision matrix was constructed using equation 2. Calculated matrix has been shown in Table 7.

At the fifth step of the TOPSIS method, the positive ideal solution (A^+) and negative ideal solution (A^-) were determined by using equations 3, 4. Values of positive ideal solution (A^+) and negative ideal solution (A^-) extracted from normalized decision matrix have been shown below as two vectors.

After identifying positive ideal solution (A^+) and negative ideal solution (A^-) the separation of each alternative from the ideal solution are given using equations 5, 6. Distance of each alternative from the ideal solution can be seen in Table 9. Relative closeness of the alternatives (CC_j) to the ideal solution (A_j) were defined by the last equation with respect to A^+. Results of calculation are shown in Table 9.

The results of TOPSIS analysis are summarized in Table 10 and Figure 1. Based on the closeness coefficient to the ideal solution (Cc_j value) ranking of the preference order of all alternatives in descending order is as below. According to the last step, the best alternative for weft knitting machine is selected as sample No.16 with closeness coefficient of 0.815 and the worst alternative is sample No.23 with closeness coefficient of 0.137

This study shows that statistical analysis is not able to present the best alternative (according to the Duncan Multiple Range Test) but TOPSIS approach is a powerful method in such kind of the problems due to considering producers preferences. Although sample No.16 has the best performances for only one of the criteria (CV%), but it is in the first order in the final ranking due to considering proposed weight of the criteria. According to the TOPSIS final ranking, yarn sample spun at processing condition in which distance between back and middle rolls is 8 mm, delivery speed is 750m/min and break draft is 1.41 has the best performance.

Sensitivity Analysis: As stated, the first step in TOPSIS algorithm is introducing relative importance of each criterion and calculating its weight. Values of the relative importance are expressed by decision makers. Since they can not fix certainly their opinion, it is important to know the effect of deviation in these values on final ranking.

To test this influence, sensitivity analysis is conducted. The idea of sensitivity analysis is decreasing and increasing all the weights of the criteria (5%, 10%, 15%, 20%) according to the equation 8 and repeating TOPSIS approach with new values.

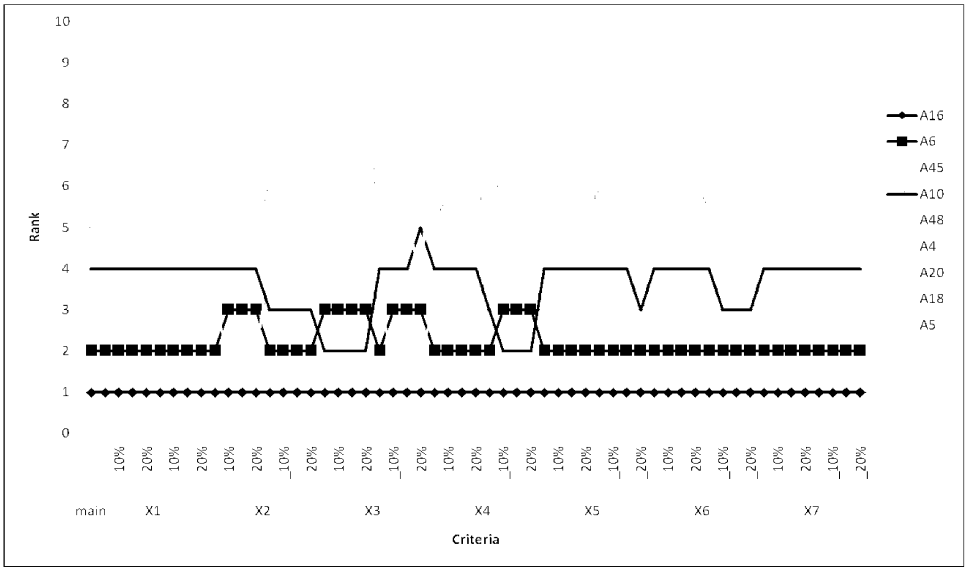

Fig. 2: Ranking the preference order of 6 more important alternatives after sensitivity analysis

$$W_i^{new} = W_i \pm \alpha W_i \ \& \ \alpha = \{0.05, 0.1, 0.15, 0.2\} \quad (8)$$

Since 7 criteria were used in this study therefore, 56 combinations are analyzed with each combination stated as a condition. The main condition in Table 10 expresses the original result of the case study. Figure 2 illustrates the graphical representation for only 9 more important alternatives of these results that were in prior final ranking due to limitation.

According to the Figure, it was concluded that, ranking of 4 more important alternatives (A16, A6, A45, A10) is approximately as same as previous main ranking. Alternatives show a straight or nearly straight line trend and their position in new ranking is stable while considered weight for each yarn property changes.

CONCLUSION

The purpose of the study is to test the applicability of TOPSIS approach in obtaining optimum draw frame process condition for rotor spun yarn intended to be used in weft knitting machine. TOPSIS approach enables the decision maker to give weights to the criteria and determines their ranking according to his preferences and desired final product characteristics.

Forty eight different yarn samples were spun by considering three factors in draw frame (passage No.1). Qualitative parameters of the samples were assessed according to the standard methods. Then, these characteristics were evaluated with the purpose of using the yarn in weft knitted fabric and to increase machine efficiency. Relative steps of the TOPSIS algorithm were executed for available data and finally the ranking of the alternatives were performed based on the mentioned goal. Sensitivity analysis was also done in order to investigate the stability of the final ranking. Moreover, the same analysis was done using statistical method. Study showed that, TOPSIS is able to present the best condition. Yarn sample spun when distance between back and middle rolls is 8 mm, delivery speed is 750m/min and break draft is 1.41 has the best performance among available alternatives. As results of this method being dependent on preferences of the decision maker, results put forward in this study are valid only for this particular case and may be completely different for another decision maker and final goal.

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