Selecting Doffing Tube Components for Rotor-Spun Yarn for Weft Knitted Fabrics Using Multi-criteria Decision-making Approach with Interval Data

Abdolrasool Moghassem[1], Alireza Fallahpour[2]

[1]Department of Textile Engineering, Qaemshahr Branch, Islamic Azad University, Qaemshahr, IRAN

[2]Department of Management, Firoozkooh Branch, Islamic Azad University, Firoozkooh, IRAN

Correspondence to:
Abdolrasool Moghassem email: moghassem.ar@qaemshahriau.ac.ir

ABSTRCT

Selecting appropriate spinning conditions according to the properties of the final yarn is an intricate aspect and is inherently a multi-criteria decision-making (MCDM) problem. In recent years, various MCDM approaches have been used for solving such kind of the problems with exact value of the attributes. But, values of the properties for a yarn are affected by some factors such as specimen length, number of tests and experimental conditions. Therefore, decision-makers use average values instead of exact values for calculation. Considering existing difficulties in determining precisely the exact values of the attributes, their values can be considered as intervals. Therefore, in the present study, appropriate components of the doffing tube and its adjustment for rotor spun yarn intended to be used for weft knitted fabric were selected by extended version of the TOPSIS. Three important variables were considered and their performances were evaluated based on the seven quality parameters of the sixteen produced yarns. The final ranking 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.

KEYWORDS

Multi-criteria decision making – TOPSIS approach - Interval data - Rotor spun yarn - Doffing tube – weft knitted fabrics

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]. However, properties of a yarn are affected by characteristics of the fibers, spinning preparation processes and conditions.

In rotor spinning system, the three important parameters, viz., the nozzle, torque stop, and distance between nozzle and rotor, occurring between the peeling point and the delivery roller have a great influence in obtaining optimum yarn quality necessary for subsequent processes and end product properties[2].

The nozzle is one of the most important components of the spin-box that affects yarn properties and spinning stability. To reduce end breakage, the yarn must have sufficient twist at the peeling point. The twist is created by the help of a nozzle. Yarn, drawn from the rotor groove, makes a 90^0 turn inside the nozzle. The rotation of the yarn around the inner wall of the nozzle creates additional false twists on the yarn between the rotor groove and yarn draw-off tube[2, 3].

False twist insertion is a function of the friction between the yarn surface and extractive nozzle. In addition to causing tension breaks, higher rotor speeds increase the false twist effect and when smooth nozzles are used in this condition, over-twisting and yarn ruptures can occur. Therefore, grooves are cut or pressed into the nozzle, which briefly lift the yarn off the nozzle surface[2].

Residual twists or differences between machine and yarn twists increase linearly when the nozzle funnel diameter increases or for a determined funnel diameter when the nozzle is grooved[4]. Tyagi *et al*[5] demonstrated that, the tenacity of cotton-acrylic yarn is closely associated with the shape of the extractive nozzle. The yarn spun with a spiral nozzle significantly exhibits lower tenacity and breaking extension than their counterparts spun with a notched nozzle[5].

Also, with cotton yarn, higher tenacity can be obtained by using a spiral nozzle[6]. Due to the increase in false twists by using extractive nozzles, the proportion of wrapper fibers increases. In contrast, the opposite results in increased bulkiness and rigidity of the yarn[5]. In addition to the low quality of the product, grooved nozzles can produce hairy and harsh yarns proportional to the number and shape of the grooves[3, 7].

Torque stop is another component that increases and saves twists between the deflecting point and rotor. The radius of the curvature of the torque stop affects the amount of increase in the twist level. Unfortunately, yarn hairiness and imperfections are increased by using a torque stop. Consequently, at the yarn peel off point, quality is improved by choosing a closer setting between the nozzle and rotor. However, less distance is a reason for increasing spinning instability[3].

Because of existing high degree of interaction between above-mentioned factors and spun yarn properties, selecting appropriate processing conditions among possible alternatives is a difficult task and a multi-criteria decision-making problem. In recent years, MCDM approaches specially, TOPSIS method have been used for solving such kind of the problems with exact value of the attributes. But, in some cases, such as yarn properties, determining precisely the exact values of the characteristics is impossible and that, as a result, their values are considered as intervals. This assumption can help decision-makers in obtaining the most preferable choice among all the possible alternatives in comparison with conventional TOPSIS methods.

However, there is not published literature that focuses on selecting the optimum spinning processing conditions using this method. Therefore, in this study, assistance in reaching acceptable solution in order to select the appropriate setting in rotor spinning machine for 30Ne rotor yarn intended to be used for weft knitted fabric will be provided by TOPSIS approach with interval data.

THE TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION WITH INTERVAL DATA

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 (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[8]. Multi-criteria decision-making may be considered as a complex and dynamic process including one managerial level and one engineering level.

TOPSIS, one of the known classical MCDM methods, 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[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[11]. Kaplan, Araz and Goktepe[2] (2006) applied ELECTRE outranking method for the selection of rotor navel. MCDM method was used to select cotton fibers and laydown in blow room[12]. The procedure of TOPSIS can be expressed in a series of steps that are: 1; Calculate the normalized decision matrix, 2; Calculate the weighted normalized decision matrix, 3; Determine the positive ideal and negative ideal solution, 4; Calculate the separation measure using the n-dimensional Euclidean distance, 5; Calculate the relative closeness to the ideal solution, 6; Ranking the preference order[9].

Considering the fact that, in some cases, determining the exact values of the attributes is difficult and that, as a result, their values are considered as intervals. Extended version of the TOPSIS approach was presented by Jahanshahloo *et al.*[8] (2006) for the interval data. Like to the conventional TOPSIS method, this algorithm can be concisely expressed in matrix format (decision matrix).

$$\begin{array}{c|c|c|c|c} & C_1 & C_2 & \cdots & C_n \\ \hline A_1 & x^L{}_{11}, x^U{}_{11} & x^L{}_{12}, x^U{}_{12} & \cdots & x^L{}_{1n}, x^U{}_{1n} \\ A_2 & x^L{}_{21}, x^U{}_{21} & x^L{}_{22}, x^U{}_{22} & \cdots & x^L{}_{2n}, x^U{}_{2n} \\ Am & x^L{}_{m1}, x^U{}_{m1} & x^L{}_{m2}, x^U{}_{m2} & \cdots & x^L{}_{mn}, x^U{}_{mn} \end{array}$$

Where, A_1, A_2, .., Am are m possible alternatives among which decision makers have to choose, C_1, C_2, …, C_n are criteria with which alternative performance are measured, x_{ij} is the rating of alternative Ai with respect to the criterion Cj and is not known exactly and only we know $x_{ij} \in [x^L{}_{ij}, x^U{}_{ij}]$ [8].

$W = [w_1, w_2, \ldots, w_n]$ where; w_j is the weight of criterion c_j. At the next steps;

- Calculate the normalized decision matrix. The normalized value $n^{-L}ij$ and $n^{-U}ij$ is calculated as:

$$n^{-L}{}_{ij} = x^L{}_{ij} \Big/ \sqrt{\sum_{j=1}^{m} x^L{}_{ij}{}^2 + x^U{}_{ij}{}^2},\ j = 1,\ldots.,m\ i = 1,\ldots,n \qquad (1)$$

$$n^{-U}{}_{ij} = x^U{}_{ij} \Big/ \sqrt{\sum_{j=1}^{m} x^L{}_{ij}{}^2 + x^U{}_{ij}{}^2},\ j = 1,\ldots.,m\ i = 1,\ldots,n \qquad (2)$$

The normalization method mentioned above is to preserve the property that, ranges of normalized numbers belong to [0, 1].

- Calculate the weighted normalized decision matrix.

$$\upsilon^{-L}{}_{ij} = \omega_i n^{-L}{}_{ij}, \qquad j = 1,\ldots,m \qquad i = 1,\ldots,n \qquad (3)$$

$$\upsilon^{-U}{}_{ij} = \omega_i n^{-U}{}_{ij}, \qquad j = 1,\ldots,m \qquad i = 1,\ldots,n \qquad (4)$$

Where ω_i is the weight of the ith attribute or

criterion, and $\sum_{i=1}^{n} \omega_i = 1$

- Determine the positive ideal solution and negative ideal solution

$$A^{-+} = \left\{\upsilon^{-}{}_1{}^{+}, \ldots \upsilon^{-}{}_n{}^{+}\right\} = \left\{\left(\max_j \upsilon^{-U}{}_{ij} \middle| i \in I\right), \left(\min_j \upsilon^{-L}{}_{ij} \middle| i \in J\right)\right\} \quad (5)$$

$$A^{--} = \left\{\upsilon^{-}{}_1{}^{-}, \ldots. \upsilon^{-}{}_n{}^{-}\right\} = \left\{\left(\min_j \upsilon^{-L}{}_{ij} \middle| i \in I\right), \left(\max_j \upsilon^{-U}{}_{ij} \middle| i \in J\right)\right\} \quad (6)$$

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

- Calculate the separation of each alternative from the positive ideal solution and negative ideal solution, using the n-dimensional Euclidean distance.

$$D^{-+}{}_j = \sqrt{\sum_{i \in I} (\upsilon^{-L}{}_{ij} - \upsilon^{-}{}_i{}^{+})^2 + \sum_{i \in J} (\upsilon^{-U}{}_{ij} - \upsilon^{-}{}_i{}^{+})^2} \quad j = 1,\ldots.,m. \quad (7)$$

$$D^{--}{}_j = \sqrt{\sum_{i \in I} (\upsilon^{-U}{}_{ij} - \upsilon^{-}{}_i{}^{-})^2 + \sum_{i \in J} (\upsilon^{-L}{}_{ij} - \upsilon^{-}{}_i{}^{-})^2} \quad j = 1,\ldots.,m \quad (8)$$

- Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_j with

respect to A^{-+} is defined as

$$R^{-}{}_j = D^{-}{}_j{}^{-} / \left(D^{-}{}_j{}^{+} + D^{-}{}_j{}^{-} \right), \qquad j = 1,\ldots,m \qquad (9)$$

Since $D_j{}^{--} \geq 0$ and $D_j{}^{-+} \geq 0$, then clearly

$R^{-}{}_j \in [0,1]$.

- Ranking the preference order.

Obviously, an alternative A_j is closer to the A^{-+} and farther from A^{--} as $R^{-}{}_j$ approaches to 1. Therefore, according to the closeness coefficient, decision-makers can determine the ranking order of all alternatives and select the best one from among a set of feasible alternatives.

MATERIALS AND METHODS

Cotton fibers with 27mm mean fiber length, 3.6 micronaire fineness and 0.85 fiber maturity index were furnished as a second draw frame sliver with linear density of 5.2ktex. The 30Ne yarn was spun on a Rieter RU04 rotor spinning machine with 900tpm. 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}.

There were four extractive nozzle types made of ceramic material. These included: spiral, grooved (4 grooves), grooved (8 grooves), and notched nozzle (4 grooves and 4 notches inside the funnel). One of the draw-off tubes had a fixed torque stop, while the other did not have a torque stop. Two different distances of 1.5 and 2 mm were used between the entry of the extractive nozzle and rotor. Sixteen different yarn samples were produced according to the specifications as shown in *Table I*.

All the yarns were tested for single strand strength and elongation on a Tesorapid3. A test specimen of 500 mm was elongated at an extension rate of 500 mm/min. The yarn evenness and imperfections were measured with the Uster tester 4 at testing speed of 400 m/min for 2.5 min and 5 samples for each yarn. The hairiness of the yarns was measured with the Premier Tester 7000. In the test, 10 samples of each yarn that were 100 m in length were examined. A statistical analysis (one way ANOVA) was carried out to analyze the differences between the test results for different groups of yarn samples at the 95% level. Also, a Duncan Procedure Multiple Range Test was performed for a better analysis.

RESULTS AND DISCUSSOIN

The results of the experiments (min and max values for each property) are shown in *Table II*. As mentioned, a one-way ANOVA test was applied to determine the effects of considered parameters on yarn quality parameters. Average values of the yarns properties were compared at 5% significance level and grouped according to the Duncan Multiple Range Test. Results of the Univariate analysis and Duncan Multiple Range Test results cannot 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 KNIABILITY

As previously mentioned, knitability, known as knitting performance of a structure for a given yarn, affects knitting machine efficiency and is of major interest to the researchers. Studies have shown that, the mechanical and physical properties of a yarn running into a large diameter circular knitting machine are an important technological parameter that affects knitting machine failure and yarn breakage[13-16]. Therefore, higher tenacity and elongation at break of the yarn and lower friction between yarn and machine surfaces such as needle are useful to reduce yarn breakage.

TABLE I. Specifications of different cotton fiber rotor yarn samples.

Sample	Extractive nozzle	Draw-off tube	Distance between nozzle and rotor (mm)
A1	4Grooves and also 4notches inside the funnel	With torque stop	2
A2	4Grooves and also 4notches inside the funnel	With torque stop	1.5
A3	4Grooves and also 4notches inside the funnel	Without torque stop	2
A4	4Grooves and also 4notches inside the funnel	Without torque stop	1.5
A5	Grooved (8 grooves)	Without torque stop	2
A6	Grooved (8 grooves)	Without torque stop	1.5
A7	Grooved (8 grooves)	With torque stop	2
A8	Grooved (8 grooves)	With torque stop	1.5
A9	spiral	With torque stop	1.5
A10	spiral	With torque stop	2
A11	spiral	Without torque stop	2
A12	spiral	Without torque stop	1.5
A13	Grooved(4 grooves)	Without torque stop	1.5
A14	Grooved(4 grooves)	Without torque stop	2
A15	Grooved(4 grooves)	With torque stop	2
A16	Grooved(4 grooves)	With torque stop	1.5

TABLE II. Quality parameters of the sample yarns (Performance values of the alternatives or decision matrix).

Criteria	T		E		CV		TP_1		TP_2		N		H	
	X_6^+		X_7^+		X_1^-		X_2^-		X_3^-		X_4^-		X_5^-	
Alternatives	x^L	x^U	x^L	x^U	x^L	x^U	x^L	x^U	x^L	x^U	x^L	x^U	x^L	x^U
A1	10.70	12.46	5.32	5.83	15.3	15.48	52	67	59	72	69	88	6.91	7.15
A2	9.62	11.11	5.00	5.47	15.44	15.61	48	64	55	79	79	96	6.97	7.17
A3	10.16	12.14	5.59	5.93	14.63	14.78	26	34	48	55	59	71	6.6	6.81
A4	9.22	11.03	4.78	5.71	14.93	15.22	46	57	54	68	58	70	7.54	7.72
A5	10.33	11.83	5.50	6.61	14.91	15.27	31	49	88	111	83	99	4.59	4.74
A6	9.63	13.05	5.06	6.05	15.00	15.27	19	33	89	106	84	109	4.96	5.18
A7	9.00	11.41	4.88	6.08	15.29	15.48	39	55	69	83	86	86	5.26	5.47
A8	10.2	11.39	5.31	6	14.94	15.16	40	57	50	63	69	83	4.73	5.09
A9	9.26	10.42	4.97	5.79	14.64	14.83	25	36	65	73	64	75	4.21	4.39
A10	5.78	12.38	4.90	6.05	14.73	14.91	33	46	44	55	50	68	4.21	4.41
A11	10.51	12.17	5.60	6.49	14.72	14.89	16	24	55	67	51	68	4.14	4.35
A12	11.03	12.25	5.81	6.48	14.44	14.62	14	25	49	56	45	53	4.08	4.25
A13	10.74	12.46	5.85	6.45	15.22	15.41	33	50	89	108	71	88	4.73	5.02
A14	10.74	13.29	5.59	6.74	14.64	14.81	14	28	66	84	66	63	4.27	4.51
A15	10.39	10.92	5.11	5.4	15.26	14.41	28	36	83	107	83	131	4.79	5.12
A16	10.94	13.07	5.96	6.55	14.76	15.01	25	36	74	90	74	111	4.96	5.27

T: Tenacity (cN/tex) E: Elongation (%) CV: Coefficient of mass variation (%) TP_1: Thin places (-50%) TP_2: Thick places (+50%)
N: Neps (+280%) H: Hairiness (h value)

However, mechanical properties of a yarn partly 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 can be correlated with yarn irregularity and the numbers of thick and thin places[17].

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[13-16].

PERFOMING 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 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. The determination of the weight requires the input of expert's 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 24 expert's opinions that were proficient in weft knitting industry. *Table III* shows results of the discussion about importance of the rotor yarn properties.

As indicated above, the first step in decision making using TOPSIS approach (with interval data) is identification of decision matrix. The performance values of the alternatives or decision matrix that is obtained from maximum and minimum values of yarn quality parameters has been shown in *Table II*.
At the next step normalized decision matrix was calculated using *Table II* and equation (1, 2). Normalized decision matrix has been shown in *Table IV*.

Importance of the criteria was determined by using expert's 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 V 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 (3, 4). Calculated matrix has been shown in *Table VI*.

At the fifth step of the TOPSIS method, the positive ideal solution (A^{-+}) and negative ideal solution (A^{--}) were determined by using equation (5, 6). Values of positive ideal solution (A^{-+}) and negative ideal solution (A^{--}) extracted from normalized decision matrix have been shown below as two vectors.

TABLE III. Intensity of the effect of yarn properties on weft 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 IV. The normalized decision matrix.

Criteria	T		E		CV		TP$_1$		TP$_2$		N		H	
	X_6^+		X_7^+		X_1^-		X_2^-		X_3^-		X_4^-		X_5^-	
Alternatives	n^{-L}	n^{-U}	n^{-L}	n^{-U}	n^{-L}	n^{-U}	n^{-L}	n^{-U}	n^{-L}	n^{-U}	n^{-L}	n^{-U}	n^{-L}	n^{-U}
A1	0.171	0.199	0.163	0.179	0.180	0.182	0.231	0.298	0.178	0.191	0.154	0.197	0.225	0.233
A2	0.154	0.178	0.153	0.168	0.181	0.183	0.213	0.285	0.170	0.210	0.177	0.215	0.227	0.234
A3	0.162	0.194	0.172	0.182	0.172	0.174	0.115	0.151	0.090	0.146	0.132	0.159	0.215	0.222
A4	0.147	0.176	0.147	0.175	0.175	0.179	0.205	0.254	0.151	0.181	0.130	0.157	0.246	0.251
A5	0.165	0.189	0.169	0.203	0.175	0.179	0.138	0.218	0.130	0.295	0.186	0.222	0.149	0.154
A6	0.154	0.209	0.155	0.186	0.176	0.179	0.084	0.147	0.087	0.282	0.188	0.244	0.161	0.169
A7	0.144	0.182	0.150	0.187	0.180	0.182	0.173	0.245	0.146	0.221	0.192	0.192	0.171	0.178
A8	0.163	0.182	0.163	0.184	0.176	0.178	0.178	0.254	0.151	0.167	0.154	0.186	0.154	0.166
A9	0.148	0.167	0.153	0.178	0.172	0.174	0.111	0.160	0.095	0.194	0.143	0.168	0.137	0.143
A10	0.092	0.198	0.150	0.186	0.173	0.175	0.147	0.205	0.122	0.146	0.112	0.152	0.137	0.143
A11	0.168	0.195	0.172	0.199	0.173	0.175	0.071	0.106	0.063	0.178	0.114	0.152	0.135	0.141
A12	0.176	0.196	0.178	0.199	0.170	0.172	0.062	0.111	0.066	0.149	0.100	0.118	0.133	0.138
A13	0.172	0.199	0.180	0.198	0.179	0.181	0.147	0.222	0.133	0.287	0.159	0.197	0.154	0.163
A14	0.172	0.213	0.172	0.207	0.172	0.174	0.062	0.124	0.074	0.223	0.148	0.141	0.139	0.147
A15	0.166	0.175	0.157	0.166	0.179	0.169	0.124	0.160	0.095	0.284	0.186	0.293	0.156	0.167
A16	0.175	0.209	0.183	0.201	0.173	0.176	0.111	0.160	0.095	0.239	0.166	0.249	0.161	0.172

TABLE V. 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	0.0850
Elongation (%)	3.875	0.0752
CV (%)	9.750	0.1893
Thin (-50%)	4.625	0.0898
Thick (+50%)	9.750	0.1893
Nep (+280%)	9.250	0.1796
Hairiness (H)	9.875	0.1917

TABLE VI. The weighted normalized decision matrix.

Criteria	T		E		CV		TP$_1$		TP$_2$		N		H	
	X_6^+		X_7^+		X_1^-		X_2^-		X_3^-		X_4^-		X_5^-	
Alternatives	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$	$\bar{\upsilon}^{L}$	$\bar{\upsilon}^{U}$
A1	0.014	0.016	0.012	0.013	0.034	0.034	0.020	0.026	0.026	0.032	0.027	0.035	0.043	0.044
A2	0.013	0.015	0.011	0.012	0.034	0.034	0.019	0.025	0.024	0.035	0.031	0.038	0.043	0.044
A3	0.013	0.0165	0.012	0.013	0.032	0.032	0.010	0.013	0.021	0.024	0.023	0.028	0.041	0.042
A4	0.012	0.015	0.011	0.013	0.033	0.033	0.018	0.022	0.024	0.030	0.023	0.028	0.047	0.048
A5	0.014	0.016	0.012	0.015	0.033	0.034	0.012	0.019	0.039	0.049	0.033	0.039	0.028	0.029
A6	0.013	0.017	0.011	0.014	0.033	0.034	0.007	0.013	0.039	0.047	0.033	0.043	0.031	0.0324
A7	0.012	0.015	0.011	0.014	0.034	0.034	0.015	0.022	0.030	0.037	0.034	0.034	0.032	0.034
A8	0.013	0.015	0.012	0.013	0.033	0.033	0.016	0.022	0.022	0.028	0.027	0.033	0.029	0.031
A9	0.012	0.014	0.011	0.013	0.032	0.033	0.010	0.014	0.029	0.032	0.025	0.030	0.026	0.027
A10	0.007	0.016	0.011	0.014	0.032	0.033	0.013	0.018	0.019	0.024	0.020	0.027	0.026	0.027
A11	0.014	0.016	0.012	0.015	0.032	0.033	0.006	0.009	0.024	0.030	0.020	0.027	0.025	0.027
A12	0.015	0.016	0.013	0.015	0.032	0.032	0.005	0.010	0.021	0.025	0.018	0.021	0.025	0.026
A13	0.014	0.016	0.013	0.014	0.033	0.034	0.013	0.020	0.039	0.048	0.028	0.035	0.029	0.031
A14	0.014	0.018	0.012	0.015	0.032	0.033	0.005	0.011	0.029	0.037	0.026	0.025	0.026	0.028
A15	0.014	0.014	0.011	0.012	0.034	0.032	0.011	0.014	0.037	0.047	0.033	0.052	0.029	0.032
A16	0.014	0.017	0.013	0.015	0.032	0.033	0.010	0.014	0.033	0.040	0.029	0.044	0.031	0.032

TABLE VII. Values of positive and negative ideal solution.

Ideal solution	CV% X_1^-	Thin places X_2^-	Thick places X_3^-	Neps X_4^-	Hairiness X_5^-	Tenacity X_6^+	Elongation X_7^+
A^{-+}	0.0321	0.0096	0.0246	0.0213	0.0265	0.0181	0.0156
A^{--}	0.0348	0.0268	0.0497	0.0527	0.0483	0.0078	0.0110

After identifying positive ideal solution (A^{-+}) and negative ideal solution (A^{--}), the separation of each alternative from the ideal solution are given using equations 7, 8. Distance of each alternative from the ideal solution can be seen in *Table VIII*. Relative closeness of the alternatives ($R^{-}{}_{j}$) to the ideal solution were defined by the last equation with respect to A^{-+} . Results of calculation are shown in *Table IX*.

The results of TOPSIS analysis are summarized in *Table IX* and *Figure 1*. Based on the closeness coefficient to the ideal solution ($R^{-}{}_{j}$ 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.12 with closeness coefficient of 0.9349 and the worst alternative is sample No.13 with closeness coefficient of 0.0361.

According to the final ranking, yarn sample spun by using spiral nozzle, doffing tube without a torque stop and closer setting between nozzle and rotor has the best performance. Also, yarn sample spun by using a nozzle with 4Grooves, doffing tube without a torque stop and closer setting has the worst performance based on the TOPSIS ranking.

TABLE VIII. Distance of each alternative from the positive and negative ideal solution.

Alternative	Distance from positive ideal ($D^{-+}{}_{j}$)	Distance from negative ideal ($D^{--}{}_{j}$)
A1	0.0301	0.0362
A2	0.0324	0.0346
A3	0.0187	0.0452
A4	0.0279	0.0405
A5	0.0333	0.0340
A6	0.0334	0.0350
A7	0.0245	0.0333
A8	0.0198	0.0436
A9	0.0146	0.0443
A10	0.0154	0.0522
A11	0.0093	0.0517
A12	0.0038	0.0551
A13	0.9683	0.0362
A14	0.0144	0.0462
A15	0.0401	0.0341
A16	0.0295	0.0387

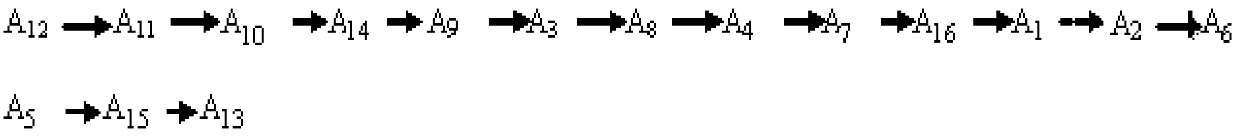

FIGURE 1. Ranking the preference order (descending) of all alternatives.

TABLE IX. Relative closeness coefficient of each alternative to the ideal solution.

Alternative	Relative closeness coefficient ($R^{-}{}_{j}$)	Alternative	Relative closeness coefficient ($R^{-}{}_{j}$)
A1	0.5459	A9	0.7514
A2	0.5165	A10	0.7714
A3	0.7069	A11	0.8464
A4	0.5921	A12	0.9349
A5	0.5054	A13	0.0361
A6	0.5117	A14	0.7613
A7	0.5757	A15	0.4591
A8	0.6878	A16	0.5676

SENSITIVITY ANALYSIS

As stated, the first step in TOPSIS (with interval data) algorithm is introducing relative importance of each criterion and calculating its weight. Values of the relative importance are expressed by decision-makers. Since they cannot 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 10 and repeating TOPSIS approach (with interval data) with new values.

$$W_i^{new} = W_i \pm \alpha W_i \;\; \& \;\; \alpha = \{0.05, 0.1, 0.15, 0.2\} \qquad (10)$$

Since seven criteria were used in this study therefore, 56 combinations are analyzed with each combination stated as a condition. The main condition in *Table IX* expresses the original result of the case study. *Table X* shows relative closeness coefficient of each alternative and new ranking after changing all the weights. As can be seen in *Table X*, new final rankings of the alternatives are as same as original final ranking and it is due to considering exact values of the alternatives in TOPSIS algorithm with interval data instead of mean values. Stability of the original ranking after changing all the weights between -20% and +20% is the preference and advantage of this extended version of the TOPSIS method. This stability is not seen when decision-makers use conventional TOPSIS algorithm[18].

CONCLUSION

In this study, the applicability of an extended version of TOPSIS approach in which exact values (interval data) of the alternatives are considered instead of mean values were tested in obtaining appropriate doffing tube components and its adjustment for rotor spun yarn intended to be used in weft knitting machine.

Sixteen different yarn samples were spun by considering three factors in spin box. 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 with interval data 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.

This study shows that this method is able to present the best condition among possible alternatives. Yarn sample spun by using spiral nozzle, doffing tube without a torque stop and closer setting between nozzle and rotor has the best performance. Also, proposed final ranking is stable even for the weights 20% more and less than original weights due to the use of exact values of the alternatives in this method. This stability is not obtainable in conventional TOPSIS method that uses mean values of the 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.

TABLE X. Results of the sensitivity analysis and new final ranking.

Original ranking	Decrease in weight							
	-5%		-10%		-15%		-20%	
	R^-_j	Rank	R^-_j	Rank	R^-_j	Rank	R^-_j	Rank
12	0.9341	12	0.934	12	0.934	12	0.934	12
11	0.846	11	0.846	11	0.846	11	0.846	11
10	0.771	10	0.771	10	0.771	10	0.771	10
14	0.761	14	0.761	14	0.761	14	0.761	14
9	0.751	9	0.751	9	0.751	9	0.751	9
3	0.706	3	0.706	3	0.706	3	0.706	3
8	0.687	8	0.687	8	0.687	8	0.687	8
4	0.592	4	0.592	4	0.592	4	0.592	4
7	0.575	7	0.575	7	0.575	7	0.575	7
16	0.567	16	0.567	16	0.567	16	0.567	16
1	0.545	1	0.545	1	0.545	1	0.545	1
2	0.516	2	0.516	2	0.516	2	0.516	2
6	0.511	6	0.511	6	0.511	6	0.511	6
5	0.505	5	0.505	5	0.505	5	0.505	5
15	0.459	15	0.4591	15	0.459	15	0.459	15
13	0.036	13	0.034	13	0.039	13	0.030	13
	Increase in weight							
	+5%		+10%		+15%		+20%	
Original ranking	R^-_j	Rank	R^-_j	Rank	R^-_j	Rank	R^-_j	Rank
12	0.934	12	0.934	12	0.934	12	0.934	12
11	0.846	11	0.846	11	0.846	11	0.846	11
10	0.771	10	0.771	10	0.771	10	0.771	10
14	0.761	14	0.761	14	0.761	14	0.761	14
9	0.751	9	0.751	9	0.751	9	0.751	9
3	0.706	3	0.706	3	0.706	3	0.706	3
8	0.687	8	0.687	8	0.687	8	0.687	8
4	0.592	4	0.592	4	0.592	4	0.592	4
7	0.575	7	0.575	7	0.575	7	0.575	7
16	0.567	16	0.567	16	0.567	16	0.567	16
1	0.545	1	0.545	1	0.545	1	0.545	1
2	0.516	2	0.516	2	0.516	2	0.516	2
6	0.511	6	0.511	6	0.511	6	0.511	6
5	0.505	5	0.505	5	0.505	5	0.505	5
15	0.459	15	0.459	15	0.459	15	0.459	15
13	0.037	13	0.032	13	0.041	13	0.043	13

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AUTHORS' ADDRESSES

Abdolrasool Moghassem
Department of Textile Engineering
Qaemshahr Branch
Islamic Azad University
Qaemshahr, IRAN

Alireza Fallahpour
Department of Management
Firoozkooh Branch
Islamic Azad University
Firoozkooh, IRAN