Ranking Alternatives in Rotor-Spun Knitting Process Using Extended VIKOR on Interval Data

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ABSTRACT
Assigning precise values for attributes in most engineering applications is almost impossible. It is therefore necessary to consider yarn properties as intervals. Hence, an extended version of VIKOR was employed in this study to select suitable spinning conditions for the weft knitting process among feasible alternatives. Three variables in rotor-spun box were considered and their performances were evaluated based on seven quality parameters using 16 yarn samples. The final ranking was presented according to the relative closeness coefficient of the ideal solution. Consequently, stability of the proposed final ranking was verified.

Keywords: Rotor-spun box, doffing tube, weft knitted fabrics, multi-criteria decision making, interval data, VIKOR approach

INTRODUCTION

There are three parameters in a rotor-spun box which are considered to be very important. These are the nozzle, torque stop, and distance between nozzle and rotor. These parameters have great influence on optimum yarn quality features which are responsible for the process and end product characteristics.

The nozzle determines the yarn properties and spinning stability. Hence, the nozzle provides sufficient twist at the peeling point and reduction in end breakage. In a rotor-spun box, twist is created by the nozzle. Yarns drawn from the rotor groove make a 90^0 turn inside the nozzle. The rotation of the yarn around the inner walls of the nozzle creates additional false twists on the yarn between the rotor groove and yarn draw-off [2, 3].

Furthermore, false twist insertion is a function of the friction between the yarn surface and extractive nozzle. Over-twisting and yarn rupture can occur when smooth nozzle and higher amount of rotor speed are employed simultaneously. Therefore, grooves are cut into the nozzle, which briefly lift the yarn off the nozzle surface [2, 3].

In addition, residual twist increases linearly when the nozzle funnel diameter increases or for a determined funnel diameter when the nozzle is grooved [4]. Tyagi *et.al* (1996) demonstrated that, the tenacity of cotton-acrylic yarn is closely associated with the shape of the extractive nozzle [5]. The yarn spin with a spiral nozzle significantly exhibits lower tenacity and breaking extension compared to an equivalent spin with a notched nozzle [5]. In addition, with cotton yarn, higher tenacity can be obtained by using a spiral nozzle [6]. Due to the increase in false twist by using extractive nozzle, 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 grooves [3, 7].

Torque stop increases and saves twist between the deflecting point and rotor. The radius of the curvature of the torque stop influences the amount of increment in the twist level. Unfortunately, yarn hairiness and imperfections are increased by using a torque stop. At the point of yarn peel off, quality is improved by choosing a closer setting between the nozzle and rotor. However, lower distance causes increased spinning instability [3].

Based on the relationship between the above-mentioned parameters and spun yarn properties [8], selecting appropriate processing condition among different alternatives is a difficult task and a multi-criteria decision-making (MCDM) problem. In recent years, MCDM approaches have been used in solving such kind of problems with exact values of the attributes. But, in some cases, such as in yarn properties, determining precisely the exact values of the characteristics is impossible. 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 this study, an aid towards achieving 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 extended VIKOR approach using interval data.

A Brief Overview of Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR Method)

MCDM deals with selection problems under the presence of a finite number of criteria and alternatives. MCDM is considered as a complex and dynamic process with managerial and engineering applications. For engineering problems, once a set of alternatives are available, MCDM methods are usually used to propose a solution to the decision-maker [9]. There are many research works that used MCDM approaches for solving textile problems. Satapathy and Bijwe used this method in ranking of organic fibers [10]. The technological value of the cotton fibers is determined by a hybrid method of MCDM [11]. Kaplan *et.al* (2006) applied ELECTRE outranking method to select nozzles in a rotor-spun box [2]. MCDM method was applied in the selection of cotton fibers and lay-down in blow-room [12].

VIKOR is one of the MCDM methods that have been extensively used by researchers. This algorithm was introduced by Opricovic and Tzeng for multi-criteria optimization of complex systems [13, 14]. VIKOR is a Serbian abbreviation for multi-criteria optimization and compromise solution [15]. It determines the compromise ranking list, compromise solution, and weight stability intervals for priority stability of the compromise solution achieved based on the initial weights [9]. Peng *et.al* (2011) described VIKOR method as a multi-class classification algorithm [15].

Opricovic and Tzeng illustrated multi-criteria planning of post-earthquake sustainable reconstruction [14]. A comparative analysis of VIKOR and TOPSIS approach was conducted by Opricovic and Tzeng [9]. Comparison between three analytical methods for knowledge community group-decision analysis was discussed by Chu *et.al* (2007) [16]. An expanded version of the VIKOR under fuzzy environment has been explained by researchers [17]. Kaya and Kahraman selected the best renewable energy alternative for Istanbul using an integrated VIKOR-AHP methodology [18]. In addition, Kuo and Liang combined VIKOR with GRA technique to evaluate service quality of airports under fuzzy environment [19]. Furthermore, San Cristobal used VIKOR technique to select renewable energy project in Spain [20].

In all the studies, attributes were considered as exact values or this algorithm was employed in a fuzzy environment. Fuzzy parameters are assumed to be with known membership functions and parameters with known probability distributions. In practice, it is not easy to specify the membership function or probability distribution in an inexact environment. Therefore, the use of interval numbers may serve the purpose better.

Interval data show more accuracy compared to crisp, and are more suitable for decision making in the imprecise environment. In decision making by interval data, each criterion has two quantities (minimum and maximum) which are used in decision matrix. The interval numbers do not indicate how probable it is for the value to be in the interval, nor do they indicate which of the many values in the interval is the most likely to occur. Therefore, interval numbers can be thought as:

- the concept of a real number which has been extended and regarded as a subset of the real line
- a degenerate flat fuzzy number or fuzzy interval with zero left and right spreads
- an α-cut of a fuzzy number [21]

It can be concluded that interval numbers indicate the extent of tolerance or region which the parameter can possibly exist. It is supposed that in decision making with interval data, the decision matrix has the following form:

	C_1	C_2		C_n
A_1	$f^L{}_{11}, f^U{}_{11}$	$f^L{}_{12}, f^U{}_{12}$		$f^L{}_{1n}, f^U{}_{1n}$
A_2	$f^L{}_{21}, f^U{}_{21}$	$f^L{}_{22}, f^U{}_{22}$		$f^L{}_{2n}, f^U{}_{2n}$
…	………….	…………..	….	………….
A_m	$f^L{}_{m1}, f^U{}_{m1}$	$f^L{}_{m2}, f^U{}_{m2}$		$f^L{}_{mn}, f^U{}_{mn}$

Where: $A_1, A_2, \ldots, A_m$ are *m* possible alternatives among which decision makers have to choose. C_1, C_2, …, C_n as criteria with which alternative performance are measured. f_{ij} is the rating of alternative A_i with respect to the criterion C_j and is not known exactly.

Rather, it is only known that $x_{ij} € [f^l_{ij} f^u_{ij}]$ and W_j is the weight of criterion, C_j. Fallahpour and Moghassem have described the steps of VIKOR method with exact value [1, 22]. In this study, the steps of this approach with interval numbers are explained in details.

In the first step of this method, the decision maker appoints the best and worst values of all criterion functions called positive ideal solution (PIS) and negative ideal solution (NIS) respectively.

$$A^* = \{f_1^*,\dots,f_n^*\} = \{(max_i^{f^u_{ij}} \mid j € I) \text{or} \ (min_i^{f^l_{ij}} \mid j € J)\} \quad j = 1,2,\dots,n \tag{1}$$

$$A^- = \{f_1^-,\dots,f_n^-\} = \{(min_i^{f^u_{ij}} \mid j € I) \text{ or } (max_i^{f^l_{ij}} \mid j € J)\} \quad j = 1,2,\dots,n \tag{2}$$

In these equations, I is linked with benefit criteria, J is linked with cost criteria and A^* is Positive Ideal Solution (PIS) and A^- is Negative Ideal Solution (NIS).

For the second step, the [S_i^l, S_i^u] and [R_i^l, R_i^u] are calculated as below:

$$S_i^l = \sum_{j\in I} W_j \left(\frac{f_j^* - f_{ij}^u}{f_j^* - f_j^-}\right) + \sum_{j\in J} W_j \left(\frac{f_{ij}^l - f_i^*}{f_j^- - f_j^*}\right) \quad i= 1,\dots, m \tag{3}$$

$$S_i^u = \sum_{j\in I} W_j \left(\frac{f_j^* - f_{ij}^l}{f_j^* - f_j^-}\right) + \sum_{j\in J} W_j \left(\frac{f_{ij}^u - f_i^*}{f_j^- - f_j^*}\right) \quad i= 1,\dots, m \tag{4}$$

$$R_i^l = \max \left\{W_j \left(\frac{f_j^* - f_{ij}^u}{f_j^* - f_j^-}\right) j € I, W_j \left(\frac{f_{ij}^l - f_i^*}{f_j^- - f_j^*}\right) j € J\right\} \quad i= 1,\dots m \tag{5}$$

$$R_i^U = \max \left\{W_j \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) j € I, W_j \left(\frac{f_{ij}^U - f_i^*}{f_j^- - f_j^*}\right) j € J\right\} \quad i= 1,., m \tag{6}$$

In this method, S_j and R_j are used to formulate the ranking measure. It is known that $S_i \in [S_i^l S_i^u]$ and $R_i \in [R_i^l R_i^u]$.

At the end, the interval Q_i = [Q_i^l , Q_i^u]; i= 1,… m, is calculated based on the afore-mentioned relations.

$$Q_i^l = \upsilon\left(\frac{s_i^l - s^*}{s^- - s^*}\right) + (1-\upsilon)\left(\frac{R_i^l - R^*}{R^- - R^*}\right) \tag{7}$$

$$Q_i^u = \upsilon\left(\frac{s_i^u - s^*}{s^- - s^*}\right) + (1-\upsilon)\left(\frac{R_i^u - R^*}{R^- - R^*}\right) \tag{8}$$

Where;

$S^* = min_i^{S_i^l}$, $S^- = max_i^{S_i^u}$,

$R^* = max_i^{S_i^l}$, $R^- = max_i^{S_i^u}$,

Q_i is a parameter which is selected as compromise solution. Based on the VIKOR method, the alternative that has minimum Q_i is selected as the best alternative.

υ is introduced as weight of the strategy of ‘‘the majority of criteria” (or ‘‘the maximum group utility”), and it is supposed that, $\upsilon = 0.5$

It is assumed that the interval numbers are $[a^l, a^u]$ and $[b^l, b^u]$. In order to select the minimum interval number, they are compared with each other as follows:

- If the interval numbers does not have any intersection, then minimum interval number is the one that has lower values. It means that $a^u \le b^l$, $[a^l, a^u]$ is chosen as minimum interval number.
- If both of these two numbers have the same condition, there is no difference between them.
- In situations that, $a^l \le b^l < b^u \le a^u$, minimum interval number in this manner will be selected as:
  1: If $\alpha(b^l\text{-}a^l) \ge (1- \alpha)(a^u - b^u)$, then $[a^l, a^u]$ is minimum interval number, while $[b^l, b^u]$ is used as an interval number.
  2: $[a^l, a^u]$ is minimum interval number, if $a^l < b^l < b^u < a^u$ and $\alpha(b^l\text{-}a^l) \ge (1- \alpha)(a^u - b^u)$, else $[b^l, b^u]$ is minimum interval number.

α is the optimism level of the decision maker that is between zero and 1 (0≤α≤1). For a rational decision maker, α = 0.5 and in this case the result of the comparisons obtained through the introduced method is similar to interval numbers’ comparison that has been made on the basis of mean of interval numbers [21].

MATERIALS AND METHODS

Second draw frame sliver with linear density of 5.2 ktex was prepared using cotton fibers with 27mm mean fiber length, 3.6 micronaire fineness and 0.85

fiber maturity index. The 30 Ne yarn was spun on a Rieter RU04 rotor spinning machine with 900 tpm. The opening roller was designed at the speed of 8200 t·min^{-1}. The 35 mm diameter rotor was operated at a speed of 75000 t·min^{-1}.

There were four extractive nozzle types made of ceramic material. These include spiral, grooved (4 grooves), another 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. Two different distances of 1.5 and 2mm 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 (TE, Zellweger, Switzerland). 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 Premier Tester 7000. In the test, 10 samples of each yarn (100m 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 are presented in *Table II*. Results of the Univariate analysis and Duncan Multiple Range Test results are not presented due to space constrain. Statistical analysis showed that main effect and interactive effect of the three variables on yarn properties to be significant**.**

Importance of the Yarn Quality Parameters for Knittability

Knittability of a yarn is a property which determines the ease with which the yarn can be knitted into fabric. It influences circular weft knitting machine efficiency. The mechanical and physical properties of a yarn running into the circular knitting machine are important technological parameters that influence machine efficiency. Higher tenacity and elongation at break of the yarn, and lower friction between yarn and machine surfaces such as needle are useful in order to reduce yarn breakage. Hairiness is a factor that affects friction between needle and yarn. 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 [23-26]. However, mechanical properties of a yarn depend on yarn imperfections and unevenness. The higher these imperfections and unevenness, the greater the tendency of yarn breakage occurrence [27]

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	
	F_6^+		F_7^+		F_1^-		F_2^-		F_3^-		F_4^-		F_5^-	
alternatives	f^L	f^U	f^L	f^U	f^L	f^U	f^L	f^U	f^L	f^U	f^L	f^U	f^L	f^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)

Performing VIKOR Method Using Interval Data

In order to obtain the ranking between these properties, the most important property to 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 denoted by positive sign while hairiness, coefficient of mass variation, and imperfections are denoted by negative sign.

All the alternatives were evaluated on the basis of these quality parameters which are the criteria for the VIKOR. The weights of these criteria which are necessary inputs for VIKOR application were determined according to their importance level for knittability and end breakage. Five of the criteria (coefficient of mass variation (CV%), thin places, thick places, neps, and hairiness) were required to be minimized and others (tenacity and elongation) to be maximized. Relative importance of the effective factors on machine efficiency was picked up based on 24 experts' opinion. These experts were proficient in weft knitting industry. *Table III* shows results of the interview on the importance of the rotor yarn properties and relative importance of each criterion. Relative importance of the criteria was considered from 1 to 10.

As stated previously, the first step in decision-making using VIKOR approach with interval numbers is obtaining the best and the worst values of all criterion functions called positive ideal solution (PIS) and negative ideal solution (NIS). The PIS and NIS were computed and presented in *Table IV*. In the next step, values of the $[S_i^l,\ S_i^u]$ and $[R_i^l,\ R_i^u]$ were calculated. Results of the calculation have been shown in *Table V*. The interval $Q_i = [Q_i^l\ ,\ Q_i^u]$; was computed as the last step of this approach. All the results have been presented in *Table VI*

.

TABLE III. Intensity of the effect of yarn properties on weft knitting machine efficiency (from 1-10).

Company	Tenacity (T)	Elongation (E)	Hairiness (H)	Unevenness (CV)	Thick places (TP_1)	Thin places (TP_2)	Neps (N)
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
Relative importance (RI_j)	7.375	3.875	9.875	9.750	9.750	4.625	9.250
Weight of each criterion	0.085	0.075	0.191	0.189	0.189	0.089	0.179

TABLE IV. The best A^* and the worst A_i^- values for each criterion functions (PIN and NIS).

Criteria	T	E	CV	TP_1	TP_2	N	H
type	Benefit	benefit	cost	cost	cost	Cost	cost
A^*	13.29	6.74	14.44	14	44	45	4.08
A^-	5.87	4.78	45	67	111	131	7.72

TABLE V. The values of S_j and R_j for interval data.

alternatives	S_{il}	S_{iu}	R_{il}	R_{iu}
A1	0.489	0.672	0.149	0.168]
A2	0.547	**0.750(S^-)**	0.161	0.189
A3	0.268	0.397	0.132	0.143
A4	0.436	0.632	0.182	**0.191(R^-)**
A5	0.356	0.611	0.124	0.189
A6	0.382	0.639	0.127	0.175
A7	0.444	0.626	0.137	0.168
A8	0.276	0.465	0.080	0.116
A9	0.225	0.374	0.059	0.081
A10	0.133	0.382	0.046	0.085
A11	0.117	0.292	0.045	0.072
A12	**0.035(S^*)**	0.168	**0.014(R^*)**	0.035
A13	0.394	0.601	0.127	0.180
A14	0.148	0.329	0.062	0.113
A15	0.461	0.540	0.013	0.179
A16	0.271	0.516	0.084	0.137

TABLE VI. Values of Q_j when $\alpha = 0.6$. $\upsilon = 0.50$.

Alternatives	Q_{li}	Q_{ui}
A1	0.7222	0.8748
A2	0.7967	0.9905
A3	0.5651	0.6629
A4	0.8307	0.9503
A5	0.5691	0.9322
A6	0.5913	0.8881
A7	0.6581	0.8556
A8	0.3641	0.5838
A9	0.2579	0.4096
A10	0.1701	0.4248
A11	0.1572	0.3389
A12	1.25941E-05	0.3389
A13	0.5961	0.8944
A14	0.2365	0.5132
A15	0.6460	0.8640
A16	0.3775	0.68944

DISCUSSION

From the last step in the calculation and proposed ranking approach on the employed methodology, the best alternative for weft knitting machine was found in sample 12. This is followed by samples 11 and 10 respectively. On the other hand, yarn sample spin by using spiral nozzle, doffing tube without a torque stop and closer setting between nozzle and rotor showed the best performance based on the VIKOR method with interval numbers.

Based on the results obtained in previous research [8], the yarn samples spun with draw-off tube without a torque stop exhibit more tenacity, more elongation at break, less coefficients of mass variation and, less hairiness compared with the samples spun with a draw-off tube that has a torque stop. A reduction in the distance between the nozzle and rotor leads to a reduction in elongation at break and coefficient of mass variation (CV%) for samples spun with a torque stop.

Coefficient of mass variation and hairiness of the samples spun with and without a torque stop are reduced by using a spiral nozzle. Similarly, the tenacity and elongation at break of samples spun without a torque stop increased as a result of using a spiral nozzle. Based on the simultaneous effect of all factors, it is found that samples spun with a spiral nozzle, doffing tube without a torque stop and a closer setting have the best characteristics.

Yarn properties were arranged from the minimum to maximum value using the sample code in *Table VII*. This implies that for tenacity and elongation, yarn properties were arranged from the worst to the best and for others, yarn properties were arranged from the best to the worst (left to right). The sets show that, machine parts (nozzle and torque stop) and setting (distance between nozzle and rotor) are statistically indifferent to performance with respect to yarn quality. According to the result of statistical analysis, sample 12 showed the best performance for six of the yarn properties (tenacity, elongation, CV%, thin places, nep, and hairiness) and the best value was obtained with sample 10 for the remaining property (thick places). However, the difference between the obtained values for thick places in samples 12 and 10 is not statistically significant.

Sensitivity analysis was conducted by changing values of υ or the weight of the strategy “of the majority of the criteria”. The approach adopted in the sensitivity analysis involved decreasing and increasing υ value from zero to one by 0.1. Since seven criteria were used in this study, therefore 70 combinations were analyzed with each combination stated. The main condition given in *Table VI* presents the original result of the case study. *Table VIII and Table IX* present the results of the sensitivity analysis. According to the result of the sensitivity analysis, ranking of more important alternatives (A12, A11, A10) is approximately as same as the previous main ranking.

TABLE VII. Statistical analysis results of the problem.

Yarn properties	Sample code
Tenacity (cN/tex)	(4),(9,8,7,3), (8,7,3,5,1), (7,3,5,1,2,10,13,15), (3,5,1,2,10,13,15,14,11,6,16), (15,14,11,6,16,12)
Elongation (%)	(4), (1,2,9,8,6,3,7,15,10), (2,9,8,6,3,7,15,10,5), (7,15,10,5,13,16), (5,13,16,14,11), (13,16,14,11,12)
CV (%)	(12), (3,14,9,11,10), (11,10,16), (8,4,5,6), (13,15,7,1), (2)
Thin (-50%)	(12,11,14), (11,14,6), (6,3,16,9,15), (15,5), (5,10,13), (7,8,4,14,2,1)
Thick (+50%)	(10,3,12,8,11), (3,12,8,11,4), (12,8,11,4,9), (8,11,4,9,1,2), (1,2,14,7), (14,7,16), (15,13,5,6)
Nep (+280%)	(12), (14,11,10,4), (11,10,4,3,9), (10,4,3,1,8,13,2), (4,3,1,8,13,2,7,5,6,16), (2,7,5,6,16,15)
Hairiness (H)	(12,11), (11,10,9), (10,9,14,5), (14,5,13), (13,8,15,6), (8,15,6,16), (16,7,3), (7,3,1), (1,2), (2)

TABLE VIII. Values of Q_j when $\alpha = 0.6$. $0 \le \upsilon \le 0.4$.

	$\upsilon = 0$		$\upsilon = 0.1$		$\upsilon = 0.2$		$\upsilon = 0.3$		$\upsilon = 0.4$	
Alternatives	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}
A1	0.7222	0.8748	0.7222	0.874895	0.7222	0.8748	0.7222	0.8748	0.7097	0.8771
A2	0.7967	0.9905	0.7967	0.990552	0.7967	0.9905	0.7967	0.9905	0.7851	0.9919
A3	0.5651	0.6629	0.5651	0.662954	0.5651	0.6629	0.5651	0.6629	0.5308	0.6405
A4	0.8307	0.9503	0.8307	0.950303	0.8307	0.9503	0.8307	0.9503	0.7920	0.9337
A5	0.5691	0.9322	0.56915	0.932219	0.5691	0.9322	0.5691	0.9322	0.5520	0.9141
A6	0.5913	0.8881	0.5913	0.888128	0.5913	0.8881	0.5913	0.8881	0.5763	0.8818
A7	0.6581	0.8556	0.6581	0.855673	0.6581	0.8556	0.6581	0.8556	0.6459	0.8515
A8	0.3641	0.5838	0.3641	0.5838785	0.3641	0.5838	0.3641	0.5838	0.3601	0.5863
A9	0.2579	0.4096	0.2579	0.4096153	0.2579	0.4096	0.2579	0.4096	0.2590	0.4188
A10	0.1701	0.4248	0.1701	0.4248592	0.1701	0.4248	0.1701	0.4248	0.1652	0.4334
A11	0.1572	0.3389	0.1572	0.3389449	0.1572	0.3389	0.1572	0.3389	0.1511	0.3417
A12	1.25E-05	0.3389	1.25E-05	0.3389449	1.25E-05	0.3389	1.25E-05	0.3389	1.67E-05	0.3417
A13	0.5961	0.8944	0.5961	0.8944285	0.5961	0.8944	0.5961	0.8944	0.5826	0.8796
A14	0.2365	0.5132	0.2365	0.5132416	0.2365	0.5132	0.2365	0.5132	0.2252	0.4986
A15	0.6460	0.8640	0.6460	0.8640272	0.6460	0.8640	0.6460	0.8640	0.6388	0.8414
A16	0.3775	0.6894	0.3775	0.6894454	0.3775	0.68944	0.3775	0.6894	0.3707	0.6870

TABLE IX. Values of Q_j when $\alpha = 0.6$, $0.6 \le \upsilon \le 1$.

Alternatives	$\upsilon = 0.6$		$\upsilon = 0.7$		$\upsilon = 0.8$		$\upsilon = 0.9$		$\upsilon = 1.0$	
	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}	Q_{li}	Q_{ui}
A1	0.6847	0.8817	0.6722	0.8840	0.6597	0.8863	0.6472	0.8886	0.7472	0.8703
A2	0.7619	0.9946	0.7502	0.9959	0.7386	0.9973	0.7270	0.9986	0.8199	0.9878
A3	0.4624	0.5957	0.4281	0.5734	0.3939	0.5510	0.3597	0.5286	0.6335	0.7077
A4	0.7148	0.9006	0.6761	0.8840	0.6375	0.8674	0.5989	0.8509	0.9079	0.9834
A5	0.5177	0.8779	0.5006	0.8598	0.4835	0.8417	0.4664	0.8236	0.6034	0.9683
A6	0.5462	0.8693	0.5312	0.8630	0.5161	0.8567	0.5011	0.8505	0.6214	0.9006
A7	0.6214	0.8433	0.6091	0.8391	0.5969	0.8350	0.5846	0.8309	0.6826	0.8639
A8	0.3521	0.5912	0.3482	0.5937	0.3442	0.5962	0.3402	0.5986	0.3720	0.5789
A9	0.2613	0.4373	0.2624	0.4466	0.2635	0.4558	0.2646	0.4651	0.2557	0.3911
A10	0.1555	0.4505	0.1507	0.4591	0.1459	0.4677	0.1410	0.4763	0.1798	0.4077
A11	0.1389	0.3474	0.1328	0.3502	0.1267	0.3530	0.1206	0.3559	0.1694	0.3332
A12	2.51E-05	0.3477	2.93E-05	0.3502	3.35E-05	0.3530	3.77E-05	0.3559	4.19E-06	0.3332
A13	0.5557	0.8501	0.5423	0.8353	0.5289	0.8205	0.5154	0.8057	0.6230	0.9239
A14	0.2026	0.4695	0.1913	0.4550	0.1800	0.4405	0.1687	0.4259	0.2591	0.5423
A15	0.6245	0.7961	0.6173	0.7735	0.6101	0.7509	0.6029	0.7283	0.6604	0.9092
A16	0.3572	0.6822	0.35053	0.67984	0.3437	0.6774	0.3370	0.6750	0.3910	0.69424

CONCLUSION

In this study, the applicability of an extended version of VIKOR approach in which interval values of the alternatives are considered instead of mean values is evaluated in order to obtain the appropriate doffing tube components and its adjustment for rotor-spun yarn intended to be used in weft knitting. Yarn samples were spun by considering three factors in the rotor-spun box. Qualitative parameters of the samples were assessed according to standard methods. Then, these characteristics were evaluated using the yarn in weft knitted fabric aimed at improving the machine efficiency. Relative steps of the VIKOR technique with interval data were carried out for available data. Finally, the ranking of the alternatives was performed. Sensitivity analysis was also conducted in order to investigate the stability of the final ranking. This study shows that this method is capable of identifying 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 showed the best performance. Also, proposed final ranking was stable even for different values of the weight of the strategy

ACKNOWLEDGEMENT

This work was sponsored by Malaysian Ministry of Higher Education High Impact Research (HIR-MOHE) Project (UM.C/HIR/MOHE/ENG/01) and the University of Malaya Research Grant Project (RG138/12AET).

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