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Assessing the Impact of Spacer Size Variations on the Ring-Spun Yarn Quality Ranking

Shahriar RAIAN[1], Subrata Kumar SAHA[1], Jamal HOSSEN[1*], Lal Mohan BARAL[1], Hosne Ara BEGUM[2], Md. Reajul ISLAM[2], Mohammad Mosharof HOSSAIN[3]

[1]Department of Textile Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh

[2]Department of Yarn Engineering, Bangladesh University of Textiles, Dhaka, Bangladesh

[3]Department of Textile Engineering, Northern University Bangladesh, Dhaka, Bangladesh

*jamalsqr@gmail.com

Article

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ABSTRACT

Spinning represents the foundational step in textile manufacturing, with yarn quality significantly influencing subsequent processes. Consequently, enhancing yarn quality remains a primary concern for spinners. Of various spinning techniques, ring spinning stands out for its blend of productivity and quality. The final ring yarn is produced by the ring frame, a machine encompassing multiple functional zones. A pivotal component within this frame is the spacer between the top and bottom aprons in the drafting zone. It modulates drafting pressure and fibre movement, directly affecting yarn quality. This research explored the impact of spacer size on yarn quality by employing seven distinct spacer sizes to produce 20 Ne cotton combed yarn. Results indicated that smaller spacer sizes often yielded inferior yarn quality. As the size increased, quality improved; however, after reaching an optimal size, further enlargement led to a decline in five key quality metrics: CV_m (%), IPI, Hairiness, Tenacity, and Elongation %. This fluctuation can be attributed to changes in fibre movement and drafting pressure in the drafting zone. The study employed Interpretive Structural Modelling (ISM), a methodology grounded in expert opinions, to rank these quality parameters in importance. Through ISM calculations, yarn tenacity emerged as the most crucial quality parameter, aligning with its significance in producing woven fabrics. Furthermore, a Cronbach's Alpha score of 0.66 underscores the robust internal consistency and interrelation attesting to the study's reliability.

KEYWORDS

ring spinning, spacer size, combed yarn, IPI, tenacity, hairiness, ISM

INTRODUCTION

Yarn manufacturing is a technique of transforming fibres into yarns. Various types of natural fibres (such as cotton, jute, and wool) and synthetic fibres (such as polyester) are transformed into yarns [1,2]. There are a lot of spinning techniques for the manufacturing of yarns. Ring spinning is a popular technique because of its smooth production efficiency and wide range of product varieties [3,4]. The basic yet intricate ring-spinning process creates yarn primarily from cotton and other staple fibres. This spinning was named after its main machine, the ring frame, which consists of various parts and zones to convert roving into yarn [5]. The drafting zone is one of the most essential zones of the ring frame. This zone uses pairs of top and bottom rollers running at varying speeds to attenuate the roving fibre strand into a thinner, more uniform structure [5]. The spacer is one of the critical components of the drafting zone [7-9]. It is a plastic material between the top and bottom apron of the drafting zone of the Ring Frame. It controls the movement of the fibres and drafting pressure in the drafting zone [10]. Spacers are classified according to their size, where the size is mainly dependent on the yarn count. It is generally proportional to the yarn fineness. Generally, the drafting operation is better handled with a more significant spacer number, yielding yarn consistency [10]. It reduces yarn quality-affecting fibre length variances, thickness, and hairiness. Remembering that the appropriate spacer size depends on fibre type, processing conditions, and yarn parameters is vital [12]. Testing and analysis of the procedure of spinning can assist in establishing the spacer size needed to achieve the desired quality of the produced yarn. However, the further increase in the spacer size negatively affects the yarn quality by decreasing the fibre orientation and applying tension throughout the drafting zone [3,13]. Thus, spacer size has to correspond to fibre and yarn properties. Each yarn type is specially based on fineness; the spacer size is carried out to get optimal yarn quality [14]. For various spinning conditions, different spacer sizes are advisable due to better orientation, arrangement, and movement of the fibres in the spinning process and the application of the drafting tension [11,15].

This study uses ISM methodology, which is a method used for evaluating intricate networks as well as comprehending the parts they have [16]. Professor Amitava Dutta developed it during the early 1970s for management science and business research. The present study is exceptionally uncommon since it seeks to implement ISM in the yarn-making industry in a way that has several potential usages of ISM. At the beginning of the process, it is essential to have the input of those knowledgeable in the field [17]. Considering this, we have profiled a group of twelve specialists from the manufacturing sector and scholars who are well-versed in the art of yarn manufacturing. These professionals come from various backgrounds (details of the expert professionals are illustrated in (Table 1). Secondly, this methodology employs a causal matrix for investigating complex structures and their connections [18]. In addition, it reveals hierarchical relationships between them, which enables the parts that make them to be prioritized according to their decreasing significance levels. A visualization illustration of the horizontal structure of the parameters is shown as the final part of the explanation. The components at the top of the hierarchy have the most significant weight, whereas the variables at the bottom have essentially little effect. Each position symbolizes an alternate importance or the amount of impact. As an immediate outcome of this, it is now simpler for experts working in the sector to ascertain which factors should be emphasized above alternatives. The choice is critical because it enables the administration to highlight the resolution of the essential issues, thereby improving the likelihood that future output will be satisfactory. The methodology portion of the analysis provides an extensive representation of all the procedures involved in those processes.

The following research issues must be addressed to successfully determine the significance of quality. The qualitative characteristics of yarn using ISM should point out the most significant qualitative factors. The statistical reliability analysis should point out the internal consistency among the data:

- What effects do various spacer sizes have on the entire spinning operation, especially the arrangement of fibres in the drafting zone and the overall characteristics of the yarn?
- Which size of the spacer has the most significant influence on overall quality?
- By what means can ISM reasoning be effectively implemented in this context?
- How can obtained data suitability testing be analysed by employing statistical reliability analysis?
- How to employ ISM to conclude the critical quality variables influencing the cotton combed yarn samples?
- Are the obtained data suitable for statistical reliability testing for the proper data consistency measurement?

Satisfying the following investigation outcomes was essential to respond to the above queries.

- To identify the size of the spacer, which exhibits minimal qualitative deviations.
- To use statistical reliability testing to determine the suitability of the obtained data.
- To rank the quality variables for the first time in this field using the ISM approach.

An overview of the ring frame machine and spacer used

In the yarn manufacturing sector, the ring machine is an instrument used for transforming the rovings directly into yarn. The ring-spinning device that spins has been around for quite some time. Considering its critical function throughout the yarn manufacturing process, it is employed in virtually every manufacturing facility that produces yarn. Two of the most common kinds of ring yarn are carded and combed yarn, with the former being distinguished primarily by its higher quality and the latter by the additional machinery required for its manufacturing. Despite this difference in yarn, the ring frame is still used similarly. This equipment undertakes several steps to produce yarn, from roving through drafting, twisting, constructing, and winding. It's renowned because it can produce an extensive variety of yarn counts (10-60 Ne) at a controllable pace of production. Ring-spinning technologies have advanced to boost output and improve yarn quality [19]. These consist of computerized mechanisms for stress and twist, equipment for monitoring for identifying defects or anomalies, and automated means for substitution bobbins. The ring-spinning frame's attractiveness belies the fact that it has numerous significant disadvantages. We'll see lower production rates compared to open-end spinning or rotor spinning. Skilled operators must also run and care for the machines appropriately. The ring spinning frame's capacity utilization to create a yarn of the highest quality suitable for various uses, including garments, household textiles and clothing, and commercial fabrics, has ensured its continued use in textile manufacturing despite its shortcomings [20]. Drafting is an essential task of the ring frame, which is somewhat done in the drafting region zone, which features six rollers, three on both top and bottom, with a two-apron drafting arrangement with the shorter length on top and the more lengthy one on the bottom [21]. The drafting region of the ring affects yarn tenacity and uniformity [15].

Plastic spacers provide space among the top and bottom aprons to draft pressure and fibre circulation during spinning [22]. Figure 2 illustrates the spacer's settings in the ring frame's drafting zone. Colour and size distinguish spacers. Colors indicate spacer sizes (Figure 1). As stated in mm, the spacer size means the distance between the top and bottom aprons [23]. In Figure 1, from the left to the right, the spacers are in size 5mm, 3.8 mm, 3.5 mm, 4.5 mm, 3.9 mm, and 5.5 mm, respectively. Spacers are sized according to fineness to optimize yarn quality parameters like evenness, imperfections, strength, hairiness, and elongation. The spacer size affects the fibre drafting force [24]. Larger spacer sizes can improve drafting force, tightening fibre grip while potentially uniformizing drafting. However, excessively controlling the fibres might cause breaks or uneven yarn [25]. Thus, the spacer size must correspond to the cotton and yarn parameters [26]. Each yarn type may have an ideal spacer size for yarn fineness. Consider varying spacer sizes for different periods of spinning conditions [27].

Figure 1. Different spacers with their colours

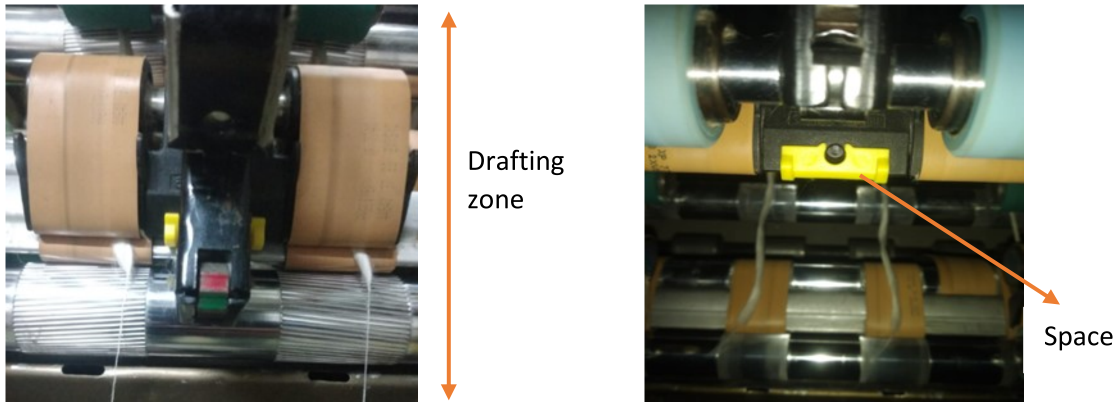


Figure 2. Settings of the spacer in the drafting zone

A brief on Interpretive Structural Modelling (ISM)

Interpretive Structural Modelling (ISM) evaluates complicated mechanisms and interconnections. It allows for discovering and visualizing those factors' hierarchy structure and interdependent relationships. It also will enable individuals to assess associations, pinpoint crucial variables, and comprehend complicated frameworks. It's utilized throughout executives, institutional investigations, engineering, planning for strategic growth, and legislation. It reveals adjustable interconnections in a hierarchical structure designated as an "ISM Digraph." All nodes and arrows compose this arrangement. These nodes denote the elements or variables within investigations, whereas indicators demonstrate how a particular factor influences another [30].

At last, it assists in determining factor influence. The research investigation reveals leading factors that impact various other factors and entirely rely on factors that other variables can affect. It illustrates the structure of the hierarchy [31].

ISM has several advantages as well as disadvantages. Its systematic and structured approach to analyzing component relationships helps visualize challenging mutual dependency. The additional advantage is that it illustrates distinct factors across various perpendicular levels, with the top one having the most influence. This method also helps real-world practitioners develop strategic plans by identifying critical criteria. A feedback loop shows strategic growth's resilience and stability. This methodology has many advantages but is based on experts' subjective input, which might lead to prejudice and inaccuracy. Second, it may not represent complicated systems with interactions that are not linear or fluctuating behaviours. Finally, this technique lacks quantifiable measurements, which may limit its utility in statistical evaluation or accurate quantity assessment [30].

An overview of the various quality parameters

CV_m (%): An analyzing parameter, CV_m (%) (Coefficient of variation to mass), determines the degree of variation or scatter of a particular characteristic within the measured population. CV_m (%) is frequently used to assess yarn evenness in quality [32].

Imperfection Index (IPI): The Imperfection Index (IPI) assesses yarn quality. It counts the yarn's flaws. It contributes to thick, thin, neps, slubs, and other defects. The magnitude and yarn quality classifies these imperfections [33].

Hairiness (H): The amount of projecting fibres or loose ends on a yarn's body is determined by hairiness. It is denoted by H. It signifies the yarn's hairiness, which might impact its appearance, consistency, and ability to perform in textile applications. The overall hairiness (H) number determines the total length of projecting fibres per unit length of yarn [32,33].

Tenacity (cN/tex): A yarn's Tenacity is its tensile strength. It assesses a yarn's most significant pulling force or load before breakage related to its linear thickness or fineness. Tenacity is typically expressed in grams per denier (g/d) or grams per tex (g/tex) [19].

Elongation (%): When exposed to pressure or stress, a single yarn lengthens by a particular amount before breaking. It assesses the yarn's load-induced stretching. The strength of the tensile test determines elongation as a percentage. A standard test clamps a yarn sample of known length at the beginning at both ends and applies an incrementally heavier load to assess its elongation [26,34].

Potential gap to the related literature and special contribution

Among the researchers in yarn manufacturing, comparing the quality parameters related to different parts of a ring frame and its different zones is prevalent for investigation. Among this topic, the study on the drafting zones and its various aspects, such as spacer size and additional drafting pressure-related topics, are also on their favourite list. Those studies include finding out the effect of spacer size by predictive modelling, the impact of dynamic pressure exerted by the optimum choice of the spacer on the quality of 17.8 tex blended yarn, study on the effect of knitted fabric-produced yarn in case of pin type spacer and impact of pressure variation due to spacer size for the production of 100% cotton carded yarn [24,28,29]. Some other studies are performed using ISM methodologies, such as predicting the ranking of the yarn quality parameters by using varied bottom apron tension positions; some other related fields, like ISM, for identifying the influential factors for a sustainable panorama, identification of significant barriers for the implementation of the sustainable supply chain, ISM for identifying CSR factors in the

Indian construction industry [35-38]. The use of ISM to prioritize the quality parameters by varying spacer size is an innovation in this related literature.

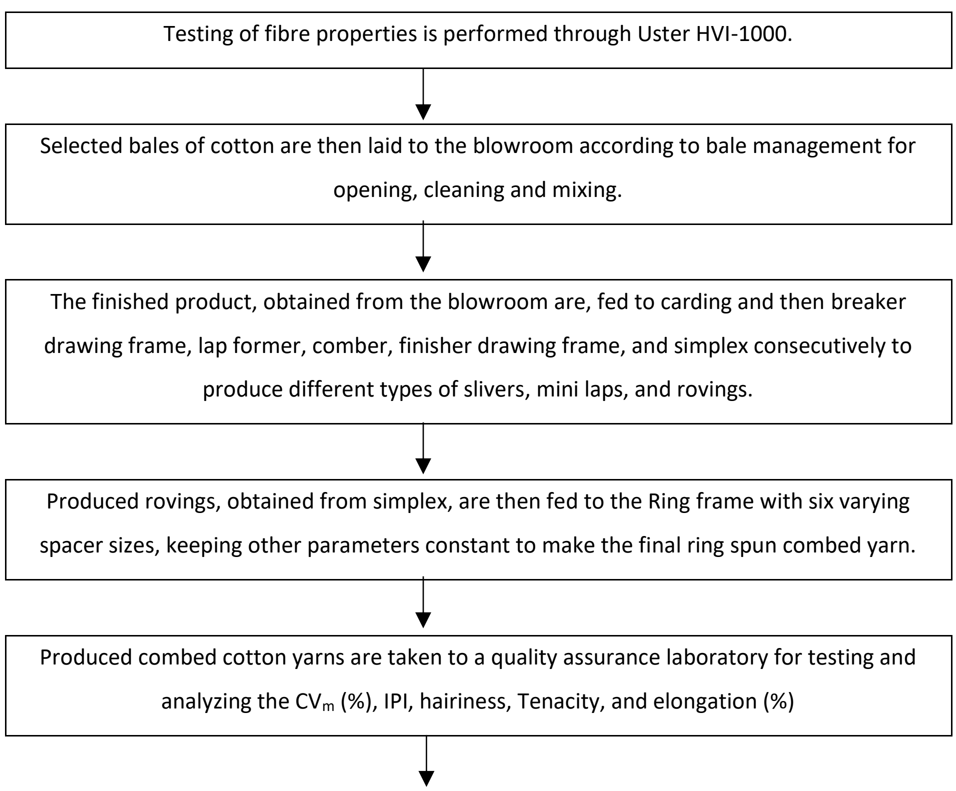
Statistical reliability analysis is also another exceptional contribution to the obtained data consistency and reliability analysis. However, this has already been used in other fields, like identifying the environmental and operational risks for the Bangladeshi spinning industry and assessing the sustainability-related risks to the textile supply chain of Bangladesh [2,37].

INVESTIGATION TECHNIQUE

This section will go over everything that needs to be mentioned about the specific steps of the procedures and the approach.

Detailed outline of the investigation

The entirety of the investigation is organized in a manner that follows the investigation's framework (Figure 2).



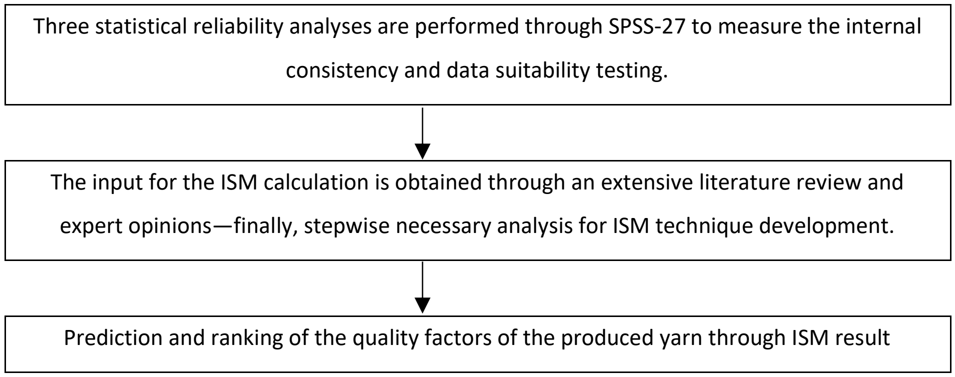


Figure 2. Detailed investigation plan

The framework of the investigation

The present investigation investigates how changes in the sizes of the spacers between the top and bottom apron of the ring frame's drafting zone affect combed yarn performance quality (Table 10). Regarding yarn quality, there are several critical criteria from scientific research and personal conversations with specialist practitioners (Table 1). The specialists' evaluation of the chosen yarn quality factors (how each influences another) for the ISM feed is necessary for creating a bilateral association network containing quality factors. Following numerous sections, utilizing those views, an illustration shows the value of quality parameters on various horizontal divisions to order or arrange them. The element at the top of the hierarchy has the most significant quality variable, while the parameter's value at the bottom of the order is the least influential. The current investigation employed reliability statistics analysis concerning data reliability and internal consistency.

Data arrangement technique

In the beginning, several qualitative variables are discovered through the relevant research study. Interviews conducted in person are subsequently employed to talk with an assembled group of specialists comprised of researchers and business leaders about the acquired data. The details about an advisory committee are displayed in Table 1. Through those conversations, specific critical characteristics of quality are established, and then data gathered from comprehensive research is evaluated based on the lengthy practical experiences of the experts. The intrinsic worth of the knowledge of experts gets greater because their significance is double. In the beginning, it makes sense to gain their insightful points of view regarding the various quality concerns involved in the manufacturing of yarn since these opinions are beneficial in validating the information obtained from the literature regarding the fundamental importance of the parameters that determine quality. In the second step, different weights of the quality attributes were selected based on their judgments to draw attention to the association between them (Table 2). Consequently, the research findings and assessments of the professionals will function as the foundation ingredients for the ISM procedure [30,36].

Table 1. The panel of researchers and industry experts and their identities

Total Specialists	Roles in related fields	Specialties	Years of Service
12	Director Operations, Director Quality, General Manager, Senior Professor	manufacture and quality control of yarn, programming, and data analytics	16-30

Reliability statistics analysis

The dependability or reliability of the measurement methods or facts used during study examinations can be evaluated using a technique known as reliability or dependability statistics analysis [38]. This technique is frequently used in subjects including psychological research, market research, and qualitative data analysis to ensure that the data gathered is trustworthy and can be applied for further analysis. Other fields that use it include the social sciences [38,39]. The data appropriateness analysis and the internal uniformity analysis are two distinct approaches that are commonly used for the intention of assessing reliability. By utilizing these dependability statistics and methods, investigators can evaluate their data's reliability and precision and determine whether it can be used for additional investigation [40,41]. Some fundamental reliability statistical analyses are Cronbach Alpha, Karl-Mayer-Olikin (KMO) test for sampling adequacy, and Bartlett's test of Sphericity (Table 11) [42-44].

Cronbach's Alpha, symbolized by α (Alpha), is a statistic used to measure a test or scale's internal consistency or reliability. It is used to assess a scale or questionnaire's internal reliability. It measures how well items on a scale link and measures a unit of measurement or factor. Significant amounts suggest internal uniformity. Where 0 denotes no association, more than 0 to 0.5 means a fragile relationship, 0.6 to 0.7 represents acceptable interconnections, 0.7 to 0.8 means good internal uniformity, and 0.8 or more represents exceptional consistency [43].

The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy is a statistic that indicates the proportion of variance in your variables that underlying factors might cause. It is an index used to evaluate the appropriateness of Factor Analysis. The analysis of data, particularly the analysis of factors, employs the Kaiser-Meyer-Olkin (KMO) metric measurements. The value of this parameter fluctuates between 0 to 1, with higher values indicating more excellent suitability for factor analysis [45]. 0 to 0.5 means inadequate samples for factor analysis, 0.5 to 0.6 means appropriateness for aspect analysis, 0.6 to 0.7 suggests moderate suitability, 0.7 to 0.8 means beneficial appropriateness, and 0.8 or greater means outstanding appropriateness [44].

Bartlett's Test of Sphericity is a statistical significance test to ensure that factor analysis is suitable for a given dataset. It checks the null hypothesis that the variables in the dataset are correlated with the population, which would make factor analysis inappropriate [46]. It determines how a given data set's correlation matrices are drastically distinct compared to an identity matrix, indicating whether or not it is acceptable for factor analysis [45].

Steps for the ISM Computations

ISM calculation is based on different stepwise analyses [36]. The whole calculation procedure is shown below.

First Step: Findings of challenge and factors

The four quality factors combined yarn will be ranked in this case. The independent factors are mass dispersion (CV_m %), imperfection index, hairiness, tensile strength (Tenacity), and elongation percentage.

Second Step: Establish the correlation among factors

The matrix below illustrates the association throughout every set of facts in Table 2. On the first row and column, for instance, O_{no} explains that there is no relationship between Tenacity and yarn irregularity values. So they do not influence each other at all. Whereas M_r score is in the second row, the second column indicates that IPI directly influences the Tenacity value. Lastly, N_r at the third row and the first column indicates that IPI influences the elongation.

Table 2. Factors of interrelationship

	Elongation %	Tenacity	Hairiness	IPI	CV_m (%)
CV_m (%)	O_{no}	M_r	M_r	Q_{rc}	
IPI	N_r	M_r	N_r		
Hairiness	O_{no}	M_r			
Tenacity	N_r				
Elongation %					

Here, CV_m (%) = Coefficient of variation concerning mass; IPI = Imperfection Index; M_r = Row (S_r) factors influence column (S_c) factors; N_r = Row (S_r) factors are influenced by column (S_c) factors; Q_{rc} = Factors of

Row (S_r) and elements of column (S_c) are influenced by each other; O_{no} = No elements of any row and column affect one another. For example, M_r at the 3rd column and 2nd row mean that CV_m (%) influences Tenacity. Similarly, O_{no} at the 1st row and 2nd means that CVm (%) and Elongation% do not affect each other.

Third Step: Structured self-interaction (SSIDM) data matrix construction

The found partnered connections between the components during Step 2 are used for developing a structure called a matrix. Let's start by demonstrating a situation with five different factors (S_1, S_2, S_3, S_4, and S_5). In this instance, we have S_5, where the Y and X axes of the matrix represent the previously mentioned variables, as depicted in Table 3. The arrow positioned in cell S_{mn} of the matrices represents the progression of the associations between the Y-dimension factor S_m and the dimension of the X-axis factor Sn. For example, the data visualization of S_{54} reveals the Y-X link between S5 and S4. The self-interaction matrices convert from qualitative information to numerical data for the following steps and are subsequently transformed into binary code. An absence of a connection is indicated by an integer of 0 in decimal notation, whereas a score of 1 signifies a relationship present (Table 4).

Table 3. Structured self-interaction data matrix (SSIDM) data construction

Variables (V_i)	1st	2nd	3rd	4th	5th
CV_m (%)		Q_{rc}	M_r	M_r	O_{no}
IPI			M_r	M_r	M_r
Hairiness				M_r	O_{no}
Tenacity					N_r
Elongation %					

Table 4. Binary transformation of the structured self-interaction data matrix

Variables (V_i)	Binary transformation	
	S_{rc}	S_{cr}
M_r	0	0
N_r	1	0
Q_{rc}	0	1
O_{no}	1	1

Here, S_{rc} is the association between row and column-wise factors, while S_{cr} is the opposite association between the row and column-wise factors.

Fourth Step: Accessibility data matrices information

The interrelated relationships between factors can be better comprehended with the accessibility data set's assistance [33]. Table 5 describes the details regarding the Accessibility data matrices set.

Table 5. Development of accessibility data matrices set

Variables (V_i)	1st	2nd	3rd	4th	5th
CV_m (%)	1	1	1	1	0
IPI	1	1	0	1	0
Hairiness	0	1	1	1	0
Tenacity	0	0	0	1	0
Elongation %	0	1	0	1	1

Fifth Step: Final accessibility data matrices specifics

ISM's organizational framework organizes factors by effect or significance, while focused links show the interactions between factors. A factor's final accessibility set includes every aspect directly or indirectly influenced by incorporating each structure level [50]. By analyzing multiple variables' ultimate accessibility sets, you can understand the system, its structure, and variable interactions. It aids in recognizing key drivers, investigating the effects of changes or interventions, and making educated decisions. The final accessibility set in ISM helps study the influence and interdependence among variables in a hierarchical structure. It streamlines the complexity of systems and supports decision-making and analysis. A complete accessibility matrix additionally demonstrates the pushing power and the dependent power. The final accessibility set's driving power shows how the system handles significant factors. It assists in determining important drivers, dependency issues, and significant aspects that influence the system's behaviour and consequences. By assessing pushing power, administrators can focus on the most considerable impact factors, improving the decision-making process and planning for strategy. At the same time, the ultimate accessibility data set's pulling power assists in assessing the system's operational factors' dependencies. It indicates their sensitivity and how alterations in influencing factors may propagate [33]. The managers may locate critical elements that need tracking, risk reduction measures, or remediation strategies by determining dependent power (Table 6).

Table 6. Construction of final accessibility data matrices

Variables (V_i)	1st	2nd	3rd	4th	5th	Pushing Power
CV_m %	1	1	1	1	0	4
IPI	1	1	0	1	0	3
Hairiness	0	1	1	1	0	3
Tenacity	0	0	0	1	0	1
Elongation %	0	1	0	1	1	3
Pulling Power	2	4	2	5	1	

Sixth Step: The splitting of the levels (LS)

In splitting the levels, finding the upper level (Level-1) requires comparing the final factors of the accessibility Matrices with the same accessibility and intersecting sets. In the ISM pyramid, the topmost factors have identical accessibility and intersect sets and are unlikely to influence other factors over their position (Table 7).

Table 7. Construction of the splitting of the levels

Variables (V_i)	Accessibility Matrices Set $A_i(V_i)$	Precedent Set $P_i(V_i)$	Intersection Set $A_i(V_i) \cap P_i(V_i)$	Layers
1st	1,2,3,	1,2,3,5,	1,2,3,	2
2nd	1,2,3,	1,2,3,5,	1,2,3,	2
3rd	1,2,3,	1,2,3,5,	1,2,3,	2
4th	4,	1,2,3,4,5,	4,	1
5th	5,	5,	5,	3

Here, Accessibility Set: The concept of "accessibility set" refers to a collection of numbers that can be derived from a single factor in further analysis.

Precedent Set: A set of variables potentially leading to one particular variable is referred to as a precedent for that variable [51].

Seventh Step: The iteration process of level splitting (LSI)

The level-splitting iteration technique refines and regulates variable levels in the hierarchy structure [51,52]. It promotes knowledge regarding the dynamics of systems and interactions among variables (Table 8).

Table 8. Construction of the iteration process of level splitting

Variables (V_i)	Accessibility Matrices Set $A_i(V_i)$	Precedent Set $P_i(V_i)$	Intersection Set $A_i(V_i) \cap P_i(V_i)$	Layers
1st	1,2,3,4,	1,2,3,5,	1,2,3,	
2nd	1,2,3,4,	1,2,3,5,	1,2,3,	
3rd	1,2,3,4,	1,2,3,5,	1,2,3,	
4th	4,	1,2,3,4,5,	4,	1
5th	1,2,3,4,5,	5,	5,	

Eight Step: Formation of the conical matrix (CM)

A conical matrix evaluates structural variable connections and interdependence [53,54]. It reveals the hierarchy structure and how the system works (Table 9).

Table 9. Construction of the Conical Matrix

Variables (V_i)	4th	1st	2nd	3rd	5th	Pushing power	Layers
4th	1	0	0	0	1	1	1
1st	1	1	1	1	0	4	2
2nd	1	1	1	1*	0	4	2
3rd	1	1*	1	1	0	4	2
5th	1	1*	1	1*	1	5	3
Pulling power	5	4	4	4	1		
Layers	1	2	2	3			

Ninth Step: Formation of the schematic diagram and ultimate model

Formation of Schematic Diagram: A schematic diagram, also called a graph with direction, shows varying structures and interconnections (Figure 3). It assists ISM in visualizing and analyzing system factors' interactions and consequences by different nodes [55-57].

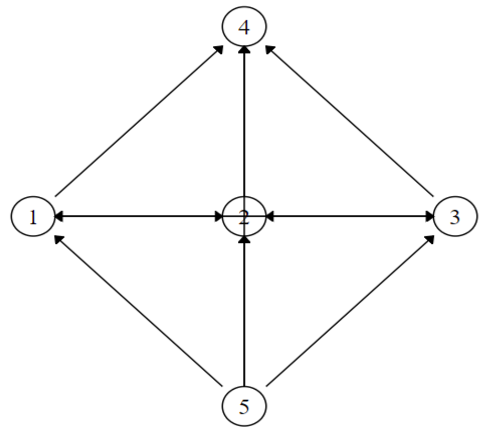


Figure 3. Schematic Diagram

Formation of Ultimate Model: ISM's ultimate model shows a system's structure of hierarchies and interactions among parameters (Figure 4). Here, level 1 is of the highest priority as it is at the top portion, whereas level 3 is given the lowest priority [53]. From the ultimate model, the value of Tenacity is given more importance, which is also in line with the required influential quality parameters of yarn for woven fabric [12].

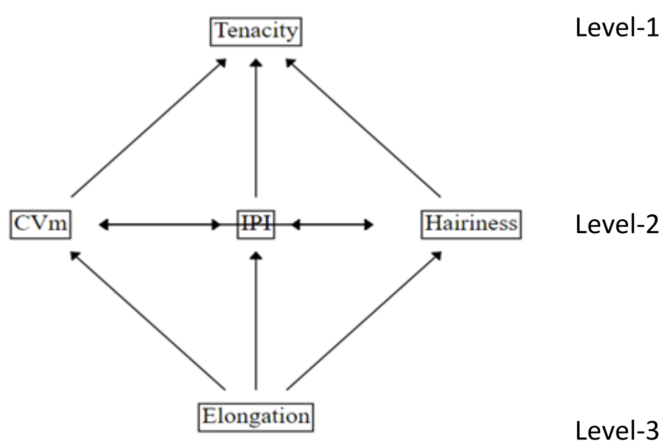


Figure 4. Ultimate Model

ISM methodology findings description

The ISM technique's ultimate model places Tenacity at the topmost layer, the first layer, and Elongation% at the bottommost layer, the third layer [57]. At the same time, the Coefficient of mass variation, imperfection index, and hairiness at the middle layer indicate that the second layer. Based on this technique, each of the variables at the topmost position or first layer is considered the most significant because these variables might affect the entire process. In contrast, the component at the bottom layer has the lowest influence and is impacted by other members. Tenacity stands at the first position, following the results of the ISM investigation. This order of importance assists managers in identifying which parameters to prioritize. Qualitative standards affect a technique's effectiveness and superiority (if we fail to ensure yarn performance, we cannot foresee outstanding textiles). This technique permits yarn manufacturers to figure out significant variables affecting quality and then implement corrective measures to enhance them [30].

At last, categorizing them according to their respective effects will have beneficial real-life applications. ISM adopts similar techniques for arriving at excellent decisions with fewer drawbacks because it commences with the perspectives of specialists in the study. In woven fabric production, the Tenacity value is of the utmost significance. Thus, our ISM technique finding has substantially contributed to the research.

RESULTS AND DISCUSSION

The Quality Assurance Laboratory uses various testing instruments, such as the Uster Evenness Tester-6 and the Uster Tensojet, to assess the manufactured 20 Ne cotton combed yarns to create woven fabrics. We evaluate these yarns against six different spacer sizes. Table 10 summarizes the findings in their entirety below. After that, we will provide our arguments based on our conclusions obtained.

Table 10. Parameters of quality for spacer sizes

Serial No.	Spacer Size (mm)	Spacer Colour	CV_m (%)	IPI	Hairiness (H)	Tenacity (cN/tex)	Elongation (%)
1	2.9	White	9.69	141	4.32	17.88	6.21
2	3.5	Grey	9.4	112	4.21	18.12	6.12
3	3.8	Blue	9.22	87	4.04	18.77	5.97
4	3.9	Black	9.05	76	3.89	18.34	5.78
5	4.5	Orange	10.03	112	4.55	17.45	6.12
6	5	Brown	10.56	154	4.67	17.34	6.23
7	5.5	Green	10.65	168	4.81	16.99	6.36

The size of the spacers in a ring-spinning machine directly impacts the amount of drafting pressure used on the fibres, affecting the fibre drafting zone in the double apron drafting system [19]. The drafting pressure could be increased using more extended spacer sizes, resulting in a firmer grip on the fibres and, presumably, more uniform drafting [22]. On the other hand, a considerable size may overcontrol the fibres, which might end up in trouble with fibre breakdown or restrict the fibre's movement scope, which may lead to irregular yarn [26]. The following information explains the impacts of different spacer sizes and their impact on the overall performance of the produced yarn.

Consequences of spacer size variations on the Coefficient of variation (CV_m%) in relationship to the quality of cotton combed yarn generated for woven fabrics:

From Table 10, it is observed that with the increase of the spacer size up to 3.9, the CV_m (%) decreased, but after that, with the rise in the spacer size, the irregularity value again increased. As we know, the size of the spacer in the double apron drafting system of the ring-spinning frame has a significant effect on the fibre drafting, the exertion of the smooth drafting pressure, and the fibre movements in the drafting zone. With the increase of the spacer size, a tighter grip of the fibres occurred because of the rise in the drafting pressure, which ensured even drafting of the fibres [20]. All these matters reduce the irregularities of fibre strands; however, further increasing the spacer size can cause overcontrol, which may be responsible for the breakage of some fibres, increasing the unevenness [58]. Lastly, there is another reason for the higher unevenness value for the excessively higher spacer size leading to more slippage of fibres as they get more space to move, causing more uneven distribution of the fibres [22].

Consequences of spacer size variations on the imperfection index in relationship to the quality of cotton combed yarn generated for woven fabrics:

Like the Coefficient of the mass variation of the produced yarn, the same trend has been observed for the total number of imperfections value, that is, the imperfection index from the result of Table 10. As we know from the previous discussion, irregularities of the yarn reduce up to a particular increase in spacer size. Imperfections have a close connection with irregularities, so imperfection values also decrease, and with further increases in spacer size, the imperfection values start to increase [20]. Another reason for that might be that a larger spacer size increases the chance of exerting more even drafting, causing more fault-free yarn. Moreover, larger spacer size increases the number of thick and thin places and neps because of the smooth gripping of fibres and uniform drafting [59]. However, overly increasing it negatively affects the fibre's movement, which may lead to uncontrolled movements [58]. Moreover, like the unevenness value, it can be said that an excessively sized spacer causes more fibre slippage to increase the imperfection values [60].

Consequences of spacer size variations on the hairiness in relationship to the quality of cotton combed yarn generated for woven fabrics

As we know, hairiness is caused by the protruding fibres coming out from the yarn surface because of the less compactness of the fibres to the main yarn body. Thus, the hairiness value H indicates the sum of the hairy fibres to the measuring length of one cm [61]. Table 9 shows that with the increase of the spacer size up to 4, the value of the total hairiness reduces, but the oversize of the spacer increases the value of hairiness. For the larger size of the spacer, fibres are smoothly controlled at the drafting zone, which causes the condensation of the protruding and short fibres to the main yarn body, causing less amount of hairiness [19]. Another problem with the smaller spacer size is that it increases the chance of fibre entanglement, causing more fibre loops, protruding fibres, and hairiness [62]. However, because of excessive spacer size, fibre control goes to an extreme level, leading to more fibre damage, causing more short fibre and hairiness problems [60].

Consequences of spacer size variations on the Tenacity in relationship to the quality of cotton combed yarn generated for woven fabrics

The simple single yarn strength value, Tenacity, is expressed as (cN/tex). From Table 10, it is observed that the magnitude of the Tenacity increases up to the spacer size 3.9 and then starts to decrease with the further increase of the spacer size. As we know, better holding of the fibres and increasing their contact area are influential in increasing the strength of the yarn [60]. Other essential parameters for increasing the yarn's strength are evenness, fewer imperfections, and protruding fibres causing hairiness. In the case of the larger spacer size, all the above attributes are achieved, like improving regularity with decreasing imperfections and hairiness. Better control of fibre is also achieved with optimum drafting of fibres at the drafting for the larger spacer size, which increases the fibre holding properties, which is also responsible for increasing the yarn strength [63]. Another importance of large spacer size is the reduction of specially thick and thin places, ensuring better evenness [47].

Consequences of spacer size variations on the elongation (%) in relationship to the quality of cotton combed yarn generated for woven fabrics

Elongation at break (%) is only the property of produced yarn, which is inversely proportional to the spacer size. That is the decrease of the elongation (%) with the increase of the spacer size up to the increasing point of the yarn strength and then started to decrease. The reason behind that smaller spacer size ensures fewer fibre controls at the drafting zone, causing more fibre slippage, which is the prime responsible issue for more stretching of yarn before rupture [20]. Because of less control of fibres, they may experience increased elongation at minimum tension; however, with the large spacer size, fibres experience proper control, reducing flexibility [63]. Uneven distribution of the fibres at the small spacer size is another responsible agent for increasing the elongation percentage of the manufactured yarn [64]. Although the further increase of the spacer size decreases the fibre control, it increases the elongation at break (%) again [65].

DISCUSSION ON THE OBTAINED RESULT FROM THE STATISTICAL RELIABILITY ANALYSIS

Cronbach Alpha, Karl-Mayer-Olikin (KMO) test for sampling adequacy, and Bartlett's test of Sphericity are three tests for the statistical reliability analysis of the data in any investigation [40,42]. These statistical reliability analyses for the obtained data in Table 10 are performed through SPSS-27 and are represented below in Table 11.

Table 11. In-depth statistical investigation into the functioning of the theoretical framework

Items	Obtained Worth	Remarks	The references
Cronbach Alpha	0.66	Acceptable interconnections among the data	(66-67)
KMO sampling sufficiency test	0.5	Appropriateness for aspect analysis and appropriateness among the data	(40,43)
Bartlett's test of Sphericity	0.00	Significant relationship among the data	(68)

From the obtained result of Table 10, the Cronbach Alpha value is 0.66, indicating acceptable interconnection among the data. A KMO value of 0.5 indicates appropriateness for aspect analysis and appropriateness among the data according to the statistical point of view. Another result obtained for Bartlett's test of Sphericity value of 0.00 (most near about 0 value indicates the most significant relationship) indicates the vital connection among the data. The obtained values of the three above tests for the statistical reliability test indicate the suitability and appropriateness of the data, so those obtained data are also statistically valid.

SIGNIFICANT OUTCOMES, RESTRICTIONS, POTENTIAL APPLICATIONS, AND CONCLUSION

Significant outcomes

For most cases, quality improves with the increase of the spacer size because of the better fibre controlling and movement, proper draft distribution, and application tension to the materials; however, the further increase in spacer size decreases the yarn quality parameters due to overcontrolling and reducing stress and fibre to fibre cohesion force. Only the exceptional value has been obtained for the elongation at the break percentage of the yarn. In the ISM technique, Tenacity is the essential quality parameter, which is also crucial in producing woven fabrics. Using the expert's opinions as the input of ISM, the result obtained from ISM is very reliable. Furthermore, the obtained result for the statistical reliability tests, especially the value of the Cronbach Alpha, is also a significant outcome of this study. To our knowledge, no researchers in this field use those techniques for statistical data analysis and data consistency testing.

Limitations

The present study was carried out using 20 Ne combed woven yarn; however, it would be more relevant to carry out for other finer counts and carded yarn so that it could be compared. In addition to the lack of availability, we could only conduct the present investigation using ten ring-frame spindles as our samples. The quantity of samples is another limitation of this study, as this value falls into the very undesirable category when evaluated using the sampling technique that is utilized in statistics. In addition, we only utilized the ISM technique for rating the quality characteristics; it will be significant if we use any other strategies for this exact reason to come to a smooth conclusion. Additionally, the number of experts has been restricted to twelve only because of the logistics of managing such as their busy schedules. If we can bring on additional knowledgeable individuals in this field, then the input of the ISM technique will be more fruitful.

Potential applications

- The overall quality of this yarn can be analyzed by learning more about the interplay between spacer size and lifetime and other factors that influence spacer size.
- Additional research on the impact of spacer size on cotton carded yarn quality or for varying cotton blends can be performed.
- More research into MCDM (Multi-Criteria Decision Making) techniques like Fuzzy DEMATEL (Decision-Making Trial and Evaluation Laboratory), Fuzzy MICMAC (Cross-Impact Matrix

Multiplication Applied to Classification), TISM (Total Interpretive Structural Modelling), and Fish Bone Diagram for searching fundamental-cause analysis is recommended.

CONCLUSION

Yarn quality is pivotal in determining a spinning factory's success and profitability, as the subsequent textile manufacturing processes rely heavily on it. This research offers significant insights into the intricate relationship between ring frame spacer sizes and the resulting quality of cotton combed woven yarn. The study found that enhancing the spacer size to a specific threshold (3.9 mm) optimizes yarn quality, attributed to improved fibre control. However, the quality diminishes beyond this size due to excessive fibre management. This finding provides a clear guideline for yarn manufacturers in selecting the optimal spacer size.

Leveraging the ISM calculations, yarn producers can better understand and prioritize crucial quality parameters. This knowledge aids in effectively managing and controlling these significant attributes, ensuring consistent yarn quality.

The study's statistical reliability analysis clarifies the consistency and suitability of the data collected. This enhances the credibility of the findings, making them invaluable for the industry's best practices.

In essence, this research deepens our understanding of the nuanced factors influencing yarn quality and also offers actionable insights for producers to achieve optimal results.

Author Contributions

Conceptualization – Raian S; formal analysis – Raian S, Saha SK and Hossen J; investigation – Raian S; resources – Saha SK, Hossen J and Islam MR; writing-original draft preparation – Raian S; writing-review and editing – Saha SK, Hossen J, Baral LH, Begum HA, Islam MR and Hossain MM; visualization – Saha SK, Hossen J, Baral LH, Begum HA and Hossain MM; supervision – Saha SK, Hossen J, Baral LH, Begum HA, Islam MR and Hossain MM. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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