Textile & Leather Review

ISSN 2623-6281 | www.tlr-journal.com | 10.31881/TLR

Prioritizing the quality parameters of cotton carded knit yarn by varying tensions of the bottom aprons of the ring frame

Shahriar Raian, Sormin Akter, Lal Mohan Baral

How to cite: Raian S, Akter S, Baral LM. Prioritizing the quality parameters of cotton carded knit yarn by varying tensions of the bottom aprons of the ring frame. Textile & Leather Review. 2023; 6:284-305. https://doi.org/10.31881/TLR.2023.046

How to link: https://doi.org/10.31881/TLR.2023.046

Published: 20 June 2023

Prioritizing the quality parameters of cotton carded knit yarn by varying tensions of the bottom aprons of the ring frame

Shahriar RAIAN[1*], Sormin AKTER[2], Lal Mohan BARAL[1]

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

[2]Department of Fashion Design and Apparel Merchandising, Anwar Khan Modern University, Dhaka, Bangladesh

*raian.te@aust.edu

Article

https://doi.org/10.31881/TLR.2023.046

Received 14 May 2023; Accepted 15 June 2023; Published 20 June 2023

ABSTRACT

The forces exerted on fibres during drafting in the drafting zone with the upper and bottom aprons of the Ring Frame significantly impact the yarn quality. Aprons are crucial in manipulating fibres by facilitating movement and directing them toward the primary drafting area. From these two aprons, the bottom apron's tension is changed by changing tension spring bar groove hole positions. There is no scope for changing such settings in the case of top aprons. This research aims to achieve high-quality cotton carded knit yarn by selecting an appropriate bottom apron tension due to the significant role in proper drafting and twist insertion at the time of the manufacturing process directly affecting produced yarn's strength, evenness, imperfections, and hairiness properties. To fulfil this requirement, six yarn samples are produced each time by using 5 different tensions of the bottom drafting aprons. The samples underwent quality parameter testing, including Unevenness (U)%, Coefficient of Variation (CV)%, Imperfection Index (IPI), Hairiness (H), and Count Strength Product (CSP). The findings indicated that increasing the tension of the bottom apron while maintaining positions 1, 2, and 3 reduces the occurrence of neps, variations in thickness and thinness, and imperfections. In contrast, CSP is increased due to elevated stress on the fibres. In general, maintaining an appropriate tension enhanced the quality of the yarn, and the best quality was obtained for position 3, considering all the quality variables. Moreover, by using Interpretive Structural Modelling (ISM) methodology, the pairwise relationship between the quality variables is shown. Finally, after calculation, those quality variables are arranged in three levels. According to this level, the quality parameters are ranked where the top is the highest. It is observed that Count Strength Product is at the highest level, which indicates that CSP should be given more priority. Moreover, the end use of this yarn is to produce knit items, and for the knitting yarn, CSP is one of the most influential quality variables.

KEYWORDS

ring spinning, carded yarn, CSP, IPI, bottom apron, ISM

INTRODUCTION

Converting fibres into skeins is commonly referred to as spinning or yarn production. Yarns comprise synthetic and natural fibres, such as nylon, polyester, cotton, wool, and silk [1]. Manufacturing yarn through mechanical techniques necessitates using energy, generating solid waste, dust, and noise [3,4]. This falls under the purview of the textile sector. Creating yarn from the fibre is a continuous process that entails a sequence of steps, including combining, cleaning, carding, drawing, roving, and spinning. Specialized machinery was employed at each stage of the yarn production process. The initial phase of the spinning procedure occurs within the blow chamber. Carding, commonly known as the "Heart of the Spinning," primarily affects yarn quality. Drawing frames have the potential to enhance fibre's parallelization and uniformity. The sliver is covertly fed into the material through a simplex frame to produce roving suitable for the ring process [5]. This machine imparts a twist to the yarn while reducing its weight and fibre count, as evidenced by its lighter cross-sectional appearance.

Preserving the draft strands' integrity is ensured, which is the measurement problem of feeding the sliver directly to the ring frame. The production process culminates in the creation of the ring. The feed material in textile production is called roving, while the material that delivers the final product is known as yarn. The drafting process is employed in the ring frame to produce the yarn. A method of enhancing the tensile strength of the yarn is achieved by incorporating a twist. It is essential to carefully draft the roving to achieve a long and thin consistency while converting roving into yarn [7]. Rollers perform this function, which has a significant role in yarn quality. The three-over-three drafting system is commonly utilized in ring frames. Drafting aprons, both top and bottom, are continuous synthetic rubber belts employed in ring frames that significantly impact the yarn quality and performance of machinery [8]. Synthetic rubber is a commonly employed material for making aprons due to its robustness, adaptability, capacity to withstand abrasion, and the presence of fibre finishing agents [9]. In the drafting zone, the tension of the bottom aprons also has an influential role in the quality of the produced yarns by influencing the optimum drafting and proper twist insertion of the produced yarn. In this way, the tension of the bottom drafting apron influences different quality parameters, such as mass variation and so variation of the distribution of the number of fibres per cross-section of yarn, causing unevenness and problems in twist insertions, which directly affect the strength of the produced yarn, tension also responsible for the fibre breakage causing yarn hairiness.

For this reason, the appropriate tension of the bottom apron is studied to achieve good yarn quality value. The leading cause of using only the tension of the bottom apron, not the top apron, is that the tension of the bottom apron can be changed by changing the tension spring bar groove hole position, which setting is absent in the case of the top apron. So the tension of the top apron is fixed [10,11]. Those qualities are reflected in the Uster Evenness tester test result of yarn quality.

The use of ISM has several importances, which ensures the uniqueness of this research to implement it in the field of yarn manufacturing. Firstly, it depends on the experts' opinions in the specific field as an initial input. For this reason, we have discussed 10 experts in the field of yarn manufacturing from industries and academic sites. Secondly, it investigates complicated structures and their connections through a relationship matrix [12,13]. It also illustrates their hierarchical relationships to prioritize components in descending order. Finally, it shows a diagram and level-wise hierarchy of the variables.

The levels indicate the rank, meaning that variables at the top level are at the highest priority or influence, and variables at the bottom level indicate the most negligible influence. In this way, it helps real-life practitioners make decisions quickly or which factors should be prioritized. This decision is also crucial as management can emphasize corrective actions on influential matters to ensure acceptable quality in the future [14-16]. The research methodology portion illustrates details of building the interrelationship matrix, the diagram formation process, and the calculations involved in ISM.

As the research involves finding out the quality and the ranking of those quality variables of yarn by using ISM to decide the most influential quality parameters, the research questions were set:

- How do different tension positions affect the entire drafting process and the overall qualities of the yarn?
- Which position is the most influential one?
- How can you successfully implement the ISM logic in this field?
- How do we find the conclusion regarding the influential quality parameters using ISM in the case of the carded yarn samples?

The research objectives are set to answer the above questions.

- To produce 30 Ne cotton carded yarn by varying the tension position of the drafting zones.
- To test the quality parameters of the produced yarn.
- To analyse and discuss the matters behind the results obtained.
- To interpret or rank the influential quality parameters.

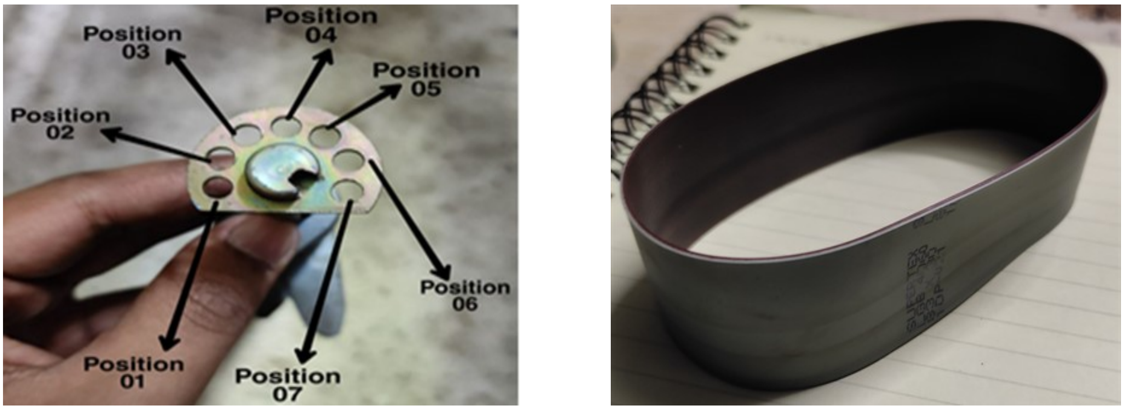
The fundamental contributions of this research to existing literature are given below:

- Finding out different suitable bottom apron tension positions of the ring spinning frame.
- Which tension position shows fewer quality deviations?
- The use of ISM methodology for the first time in this field to rank the quality variables.

Ring spinning frame

The carded yarn manufacturing process undergoes different equipment and techniques [17-19]. Ring Frame is the most basic machine to produce carded yarn manufacturing. This equipment is called Ring Spinning Machine [20-21]. The primary function of this machine is to produce yarn from previously made roving or simplex through various processes such as creeling, drafting, twisting, building, and winding. It is a widely used spinning technique because of the widest variety of yarn counts (15-50 Ne) produced with a reasonable production rate. The most crucial component of the machine that directly affects the strength and evenness of the yarn is the drafting zone of the ring frame [22], which consists of six rollers: three on top and three on the bottom, with two-apron drafting arrangement where shorter one at the top and the longer one at the bottom [23-24].

Manufacturers prefer aprons with a longer hemline because they are more convenient to swap out and pose less of a threat of inhaling loose fibres [25]. The upper aprons are held in place by a cradle mechanism at constant tension, so there is no option for changing the tension, whereas the bottom aprons are placed by a tension spring bar with 7 different groove holes with a tension bracket. By changing the holes' position, the bottom apron's tension can be adjusted. With the increase of the hole position (from 1-7), tension applied to the bottom apron also increases [25]. The fibres in the apron have been precisely aligned by grinding the outer surface. Abrasive and compressive forces act on the fibre bundle, smoothing it and creating grooves. The apron's reinforcement layer must have a certain fracture threshold to protect the tensioning equipment. Too much or too little friction can alter the fibre's motion, affecting the quality of the yarn [26].



a) b)

Figure 1. a) Tension spring bar groove hole for changing bottom apron tension; b) Bottom apron of ring frame drafting zone

Uster evenness tester

After producing yarn, it is tested using a series of testing equipment. Uster Evenness tester (Manufactured by Switzerland-based Uster Company) is widely used. This equipment is very famous for accurate and rapid testing results. This equipment has different testing slots for testing not only yarn but also some other predecessors of yarn, such as fibres, slivers, and rovings [27,28].

Quality criteria that differ

One possible way to think about the mass distribution is a normal distribution. In this case, to indicate the mass variation, the Coefficient of Variation (CV%), and unevenness (U%) are used widely [29,8].

IPI, the Imperfection Index of produced yarn, is the summation of -50 per cent of thin places, +50 per cent of the thick places, and +200 per cent of the neps in the tested yarn [30,31].

Another important yarn quality parameter is hairiness; in short, 'H,' which is mainly the numerical expression of the amount of protruding fibres coming out from the main yarn body, is a quantitative measure of how many fibres protrude from the yarn's structure in a measuring field of 1 cm length [32,33].

CSP measures cotton yarns derived from their count and lea strength. The length of the hank is calculated by winding 80 turns onto a 1.5-yard wrap reel to get a total of 120 yards. The standard unit of measurement for force is the pound-force (lbf) [34,35].

An Overview of ISM

The field of research, such as operational management and research, employs ISM, also known as interpretive structural modelling, for investigating complex systems, demonstrating coherence between parameters, and developing a judgment-supporting conceptual framework created by JN Warfield [15,16].

The potential uses of ISM encompass the following:

- When conducting strategic planning, ISM can be applied to analysing interactions among the company's purpose, mission, objectives, targets, and stakeholders
- Designers can optimize the design and boost the product's performance by fully grasping these relationships.
- ISM aims to design a system model highlighting its critical parts, connections, and interactions [36,15].

ISM's benefits and drawbacks

ISM has some unique feature that enables the researchers to make decision and flexibility of usage as it helps to simplify a complex problem to a simple one as it demonstrates the data with a diagram which is also an obvious representation. The hierarchical structure for showing the variable's level is another positive side. There are also other advantages: subsystems and clusters are straightforward to identify and most adaptable, which is suitable to fill up plenty of specific needs and requirements. On the other hand, there are also some disadvantages, such as subjective, which highly depends on the judgment of nature, and a massive amount of time required to collect expert opinions. The accuracy of the data also played an important role here though a bit of calculation is involved here to calculation [33]. Though ISM has some limitations, the positive side is triumph over the opposing side which motivates us to use this method here. This method is now lacking because of its limited applications. We know a systematic method is needed to optimize quality and productivity in the yarn production industry. ISM offers an organized structure for analysing system dynamics and identifying essential components. In the yarn manufacturing industry, showing and analysing relationships between various elements is beneficial to enhance decision-making efficiency [40]. These characteristics of ISM make it suitable for our study to apply.

A research gap and special contribution to the existing literature

Although ring spun yarn manufacturing and study on the different parameters of ring frame especially drafting zone, is widespread for researchers in this field. Among those research focuses on various issues related to the drafting zone and its different mechanisms, such as different frictional and dynamic forces acting on the yarn using various-sized spacers at the novel drafting zone, the effect of soft drafting a modified drafting system and comparison with conventional drafting system in case of 18.2 tex cotton yarn, investigation on the quality of in-ring yarns using a modified bottom apron bar with air suction in the drafting zone of the Ring Frame and finally on focusing on the parameters related to the quality of Ring yarn by varying top drafting roller pressure and varying blending ratio [37-40]. But to our knowledge, no work has been done on the different positioning of bottom drafting apron tension on the quality of the carded cotton yarn. On the other hand, the ISM methodology is another novelty of this work. Although many works have already been performed by using this methodology, no works have been performed on using this methodology on the quality-related issues for yarn manufacturing. Among those works, some are shown here; for example, ISM is used in a comprehensive literature review in production and business research for analysing their performance and productivity [41]. Other work was performed on analysing the barriers to implementing modern digital supply chain management systems for better flexibility of the overall process of an industry using ISM [42]. Identifying and analysing different risk factors for implementing green construction work is also an example of another study [43].

Moreover, a further study has been performed on identifying the barriers to implementing Industrial 4.0 in the manufacturing industry and analyses the main drivers in this issue [44]. Furthermore, an alternate study focused on Identifying and developing a risk management model for military purposes of the aircraft industry using 26 risk factors of quality issues [45]. From this above discussion, it can be said that the usages of different positioning of the bottom apron drafting positions on the quality of the carded cotton yarn and the usages of the ISM methodology give the study further uniqueness in the related literature. Here ISM is mainly used in some matters. First, it showed the pairwise relationship matrix among the quality variables. Lastly, the ranking of the variables gave the practitioners a unique indication for the actual life usages and the real concerning variable regarding yarn quality as well as the overall performance of the further processing as the yarn is the basis of the textile manufacturing, which is the exceptional contribution of this study to the related literature.

MATERIALS AND METHODS

Since the yarn is produced from a fibre, fibre is the initial raw material of this study. Different techniques to produce yarn include carded, combed, and open-end processes. This research used a ring frame to create carded yarn.

Cotton is a naturally occurring fibre obtained from the cotton ball and is distinguished by its soft and voluminous texture. The fibre predominantly comprises cellulose and features multiple amorphous regions within its composition, responsible for its increased capacity for water absorption [16-17].

Research Outline

The whole research is arranged as follows research outline.

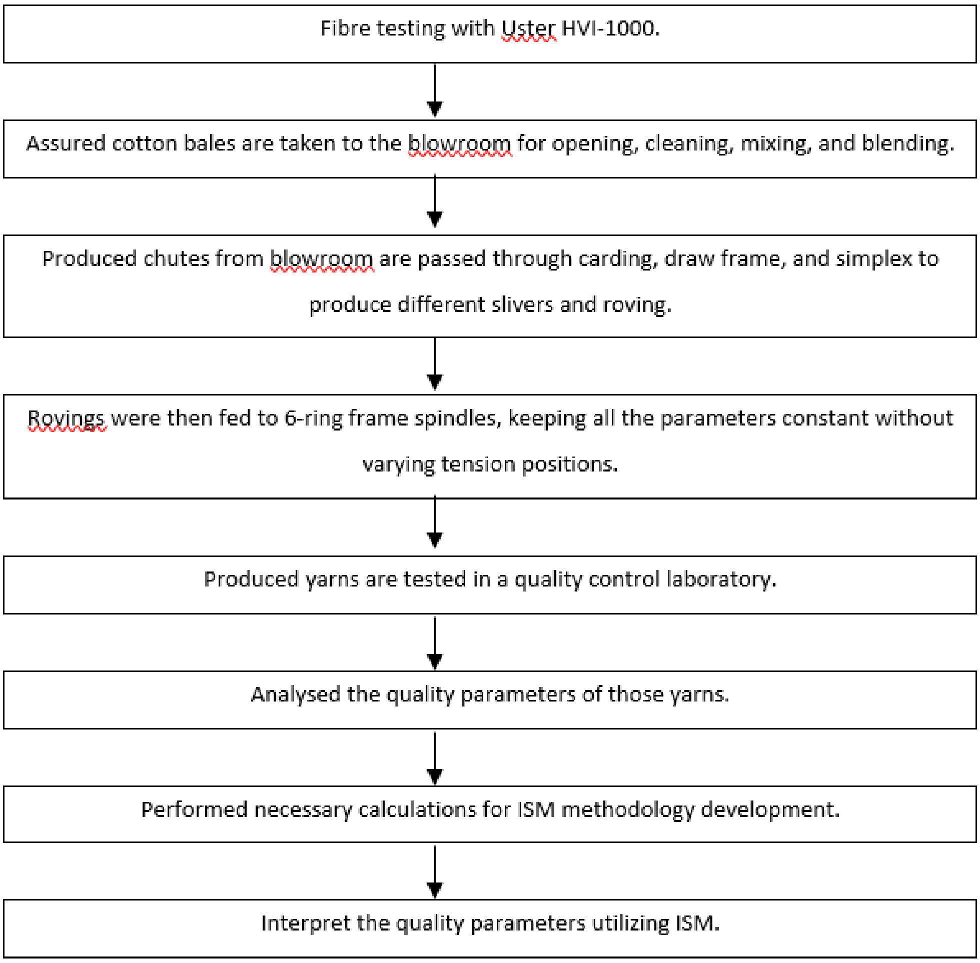


Figure 2. The outline of the research

Research framework

This research is primarily conducted on the variation of the quality parameters (Table 11) of the produced ring-spun yarn by varying the tension of the bottom apron of the ring frame's drafting zone. In the case of produced yarn quality, there are some essential criteria of the quality parameter from the literature and the expert in this field through face-to-face interviews (Table 1). Another crucial input of the experts is the comparison among the selected yarn quality parameters (that is, how one parameter affects others) for the input of the ISM, which is essential for building a pairwise relationship matrix of the quality parameters. After completing several steps, using those opinions, a diagram illustrates the quality parameters in different horizontal levels to predict the rank or prioritize the quality parameters. From this different level, the variable at the highest level indicates the highest influential parameters for the quality, whereas the parameter at the lowest level indicates the least influencing parameter.

The basic stages of ISM methodology

ISM requires the following steps:

- Identifying system elements: The initial stage in ISM is identifying all system elements you desire to represent. Physical items, processes, or conceptual ideas could be these elements.
- Creating a matrix for comparing the pairwise relationships between the variables: After finding the elements, a pairwise relationship matrix should be set up to compare the pairwise relationship of the variables. This matrix determines each pair's relationship strength.
- Designing a reachability diagram. Next is constructing a reachability matrix to indicate which system elements can impact or be influenced by others. This matrix shows hierarchical linkages.
- Generating the Digraph: Creating a directed graph or Digraph of the system using the pairwise comparison matrix and reachability matrix. Nodes represent elements, and arrows reflect relationships.
- Determining clusters: Examining the Digraph to find similar pieces. Clusters can help locate subsystems.
- Allocating levels: Finally, assigning levels to digraph nodes based on their hierarchy position. The hierarchy's top and bottom nodes have the highest and lowest levels. This stage clarifies the system's relationships and ranks the variables to determine which variable is the most and least influencing. The variables at the middle level indicate the intermediate relationship [15].

Data collection and step-by-step calculation of ISM methodology

These steps involved two sub-steps: First is collecting data from various academic and industrial experts, and then the necessary calculations are performed with the collected data as an initial input of ISM.

Details of the data collection procedure

Initially, different quality parameters are found in the related literature. Then the obtained data are discussed with a panel of experts from academics and industrialists through face-to-face interviews. Table 1 shows the details of an expert panel. From these interviews, firstly, some crucial quality parameters are extracted and consequently validated data collected from detailed literature according to the long practical experiences of the experts. The necessity of the experts is valuable because of two folds importance. Firstly, to get their valuable opinions regarding the quality issues of yarn manufacturing, which is helpful to validate the information regarding the crucial importance of the quality parameters obtained from the literature. Secondly, according to their opinions, different weights of the quality variables are determined to demonstrate the relationship among them (Details shown in Table 6). So the insights of the experts will serve as the initial inputs for the ISM methodology.

Table 1. The identities of the panel of experts (both from the academic side and industrial side)

Total Number of the Experts	Their Positions in Respective Fields	Their Expertise	Length of Experiences (in years)
7 from Industrial Side	Executive director, Senior General Manager, General Manager,	overall yarn production, quality assurance in this field, data science, and programming.	15-20
Assistant General Manager	Professor, Associate Professor	yarn manufacturing and quality control, data science.	10- 22

Step-by-step calculation procedure of ISM for prioritizing the influential quality variables

Step 1: Identification of the problem and variables

Here, the prioritization of ring-spun yarn's four quality parameters (variables) will be performed. The variables are unevenness, Imperfection Index, Hairiness, and Count Strength Product.

Step 2: Determination of the relationship between the variables

This is the crucial step, known as the making relationship between the variables or how the variables are influenced by one another. Here, the opinions of the experts are the only inputs where are (expert opinions) responsible for showing whether or not every element of the rows influences or affects every element of the columns in a pairwise manner (Table 2) [37]. This way, a relationship matrix between the row-wise and columnist variables is constructed, as shown in Table 2. This matrix is used to show the relationship between each pair of variables. For example, V_r in the first row and first column indicates that unevenness affects the count strength product of the produced yarns.

In the same way, X_{rc} in the second row and the second column indicates that the hairiness and imperfection index influences each other. At the same time, O_o indicates that unevenness and imperfection do not or less influence one another. Finally, A_r indicates any row-wise variables are affected by any column-wise variables though this type of relationship is absent in this relationship matrix [39].

Table 2. Relationship among the variables

	Count Strength Product	Hairiness	Imperfection Index	Unevenness
Unevenness	V_r	O_o	O_o	
Imperfection Index	O_o	X_{rc}		
Hairiness	V_r			
Count Strength Product				

Here, V_r=Factors in the row (R_i) affect factors in the column (R_c)

A_r= Factors in the row (R_i) are affected by the factors in the column (R_c)

X_{rc}=Row (R_i) and column (R_c)factors influence one another

O_o= Row (R_i) and column (R_c)factors do not or less influence one another

Step 3: Matrix development details for the structural self-interaction (SSIM)

A matrix is constructed based on the detected paired interactions between the factors identified in Step 2. Let's illustrate with a fictitious example involving four factors: R1, R2, R3, and R4. Here, R4, in which these factors are represented on the Y- and X-axes of the matrix (see Table 3).

Cell R_{ij} of the matrix represents the direction of the correlation between factors R_i (on the Y-axis) and R_j (on the X-axis). For instance, R_{34} depicts the relationship between R_3 and R_4 on the Y and X axes [40]. After that, the self-interaction matrix ix is converted to binary format because of qualitative data to quantitative data transformation to assist the continuation of the following steps (shown in Table 4). In binary format, 0 represents no interrelationship, and 1 represents having a proper interrelationship.

Table 3. Development of the matrix for the structural self-interaction

Factors (F_i)	1	2	3	4
Unevenness		O_o	O_o	V_r
Imperfection Index			V_r	V_r
Hairiness				V_r
Count Strength Product				

Table 4. Binary conversion of the matrix for the structural self-interaction

Items	Binary relationship	
	R_{ic}	R_{ci}
V_r	0	0
A_r	1	0
X_{rc}	0	1
O_o	1	1

Here, R_{ic} represents the relationship nature between the row-wise variable and to column-wise variable whereas R_{ci} represents the reverse which is the relationship nature between the column-wise variable and to row-wise variable.

Step 4: Matrix details for the reachability set

The reachability matrix is the binary conversion of the matrix for the Structural Self-Interaction from above Table 4. Table-8 shows the details presentation of the reachability matrix set [41].

Table 5. Development of the matrix for the reachability set

Factors	1	2	3	4
Unevenness	1	0	0	1
Imperfection Index	0	1	1	1
Hairiness	0	0	1	1
Count Strength Product	0	0	0	1

Step 5: Matrix details of the final reachability set

For illustrative and explanatory purposes only, we define the reachability matrix, antecedent, and intersection sets for the initial version of the Reachability Matrix. The Matrix of the Final Reachability Set is of interest for the digraph development. The final Reachability Matrix is constructed by grouping all variables at the same tier in rows and columns. Below Table 6 shows the details of the final reachability calculation. A final reachability matrix also demonstrates the driving power and dependence power. An element's driving power is how well it can affect or drive the other components in the overall structure. It shows how much an element affects other elements directly. It is computed by adding the reachability matrix row, which substantially impacts other factors more.

On the other hand, an element's dependence power shows how dependent it is on other components in the system's structure. It quantifies the influence of other components on an element. The reachability matrix column is summed to calculate it where higher reliance power means more dependence on other components. Analysts can identify the system's primary driving and dependent parts by assessing their driving and dependence powers. Understanding the system's structure and dynamics, identifying essential aspects, and developing improvement or decision-making techniques are all helped by this research [42].

Table 6. Development of the matrix of the final reachability set

Factors	1	2	3	4	Driving Power
Unevenness	1	0	0	1	2
Imperfection Index	0	1	1	1	3
Hairiness	0	0	1	1	2
Count Strength Product	0	0	0	1	1
Dependence Power	1	1	2	4	

Step 6: Level partitioning (LP)

Level Partitioning (LP) divides components of systems by influence and dependence. It organizes elements into layers of hierarchy that show system influence and dependence. The purpose is to discover components with higher driving power, influence, and dependence on others. The top level contains variables for which the Reachability and Intersection categories are the same in each iteration [41].

Checking the final Reachability Matrix variables with the same reachability and intersection sets identifies the top level (Level-1). R_1–R_4 occupy Level-1 in our case. The top-level factors in the ISM pyramid are those with the same reachability and intersection sets and will not lead other factors above their level.

Table 7. Development of level partitioning (LP)

Factors (Ei)	Set for Reachability Matrix R_1(Ei)	Set for Antecedent A_1(Ei)	Set for Intersection R_1(Ei)$\cap A_1$(Ei)	Levels
1	1,	1,	1,	2
2	2,	2.	2,	3
3	3,	2,3,	3,	2
4	4,	1,2,3,4,	4.	1

Reachability Set: A set of numbers that can be reached from an individual variable is referred to as a reachability set.

Antecedent Set: For each factor, an antecedent set is a set of factors potentially leading to that specific factor.

Intersection Set: It has multiple-level elements with interconnecting ranks. These system aspects are both influential and reliant. They influence and are influenced by others.

https://doi.org/10.31881/TLR.2023.046

Step 7: Level partitioning iterations (LPI)

The repeated method of improving the levels allocated to the elements within a system based on their driving power and dependent power is called level splitting repetitions in Interpretive Structural Modelling. This process is called "Level Partitioning Iterations" [41].

Table 8. Development of level partitioning (LP)

Factors (Ei)	Set for Reachability Matrix $R_1(Ei)$	Set for Antecedent $A_1(Ei)$	Set for Intersection $R_1(Ei) \cap A_1(Ei)$	Levels
1	1,4,	1,	1,	
2	2,3,4,	2.	2,	
3	3,4,	2,3,	4,	
4	4,	1,2,3,4,	4,	1

Step 8: Conical matrix (CM)

A conical matrix must be constructed before constructing the Digraph. Like the Reachability Matrix, but with the variables plotted along both axes of X and Y based on respective levels, Conical Matrix is a useful tool for data analysis. To determine how one variable is connected to others, we use Reachability Matrix.

Table 9. Development of conical matrix (CM)

Factors	1	2	3	4	Driving Power	Level
4	1	0	0	0	1	1
1	1	1	0	0	2	2
3	1	0	1	0	2	2
2	1	0	1	1	3	3
Dependence Power	4	1	2	1		
Level	1	2	2	3		

Step 9: Diagram and final model

Construction of Diagram: Elementary diagram is made with the help of using the Conical Matrix. Digrams are sets of nodes connected via arrows that point in the direction indicated by the matrix's relations (V_r, A_r, X_{rc}, or O_o). When first creating the Digraph, it considered the transitivity relationships in the Conical Matrix. The diagram's first level comprises variables from the first level of the level partitions, the second level of factors from Level 2, and so on. Arrows' directions indicate the nature of the connections between nodes.

Final Model: ISM's final model shows a system's hierarchical structure and elements' driving and dependency powers.

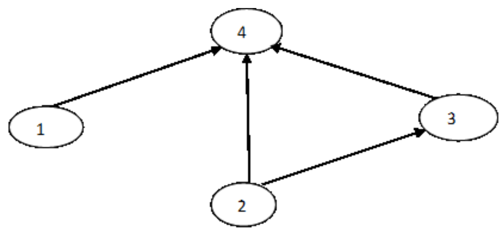


Figure 3. Elementary Diagram

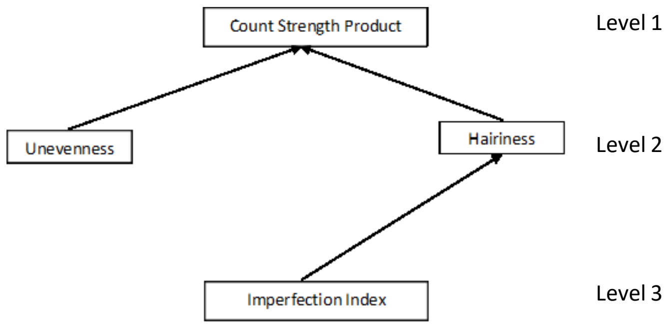


Figure 4. ISMs Final Model

Description of the results found from the ISM methodology

From the final model of the ISM methodology, we can say that Count Strength Product is at the top position, identified as Level 1 and Imperfection Index is at the bottom position, identified as Level 3. In comparison, unevenness and hairiness are in the middle position, Level 2. According to this methodology, the elements at the top position or level-1 are the most influential as they can influence the whole process, and the factor at the bottom level is the least influenced; moreover, it is influenced by others [11]. So according to the study, CSP is at the first rank. This rank helps the practitioner to make decisions for which parameters they have to give more priority. The decision regarding quality parameters is crucial because the overall efficiency of a process and the quality of further processing depends on it (if the proper quality of yarns is not ensured, quality fabrics and apparel can not be expected). From this methodology, the management of the yarn manufacturing factory can decide about the influential quality parameters, consequently making them able to take corrective actions for improving those quality variables. Finally, proper ranking according to their consequences will be helpful for real-life applicants. ISM does the same thing to take proper decisions which also has less chance of biases as it is based on the opinions of the experts of this field as the initial inputs. Furthermore, we know that in the case of knit yarn production, The CSP value is of great dominant priority [9]. So we can say that our found result from the ISM approach has a significant contribution to the related literature.

RESULTS AND DISCUSSION

Produced yarns are tested in Quality Control Lab using various testing equipment such as Uster Evenness Tester-6 and Lea Strength Tester against five tension positions. The results are listed below in Table 11. Followed by discussions of the obtained results.

Table 11. Obtained quality parameters for different tension positions of the bottom apron

Different Tension Position	Unevenness, %	Co-Efficient of Variation %	Imperfection Index	Hairiness	Count Strength Product
1	15.92	19.9	466.2	5.32	2344
2	15.25	19.06	457.2	5.10	2528
3	14.56	18.2	454.1	4.95	2743
4	15.31	19.14	463.3	5.22	2577
5	15.81	19.76	468.7	5.30	2369

As with any ring-spinning procedure, the bottom drafting apron tension affects the quality of the ring yarn produced. Obtaining correct drafting, draft distribution, and proper distribution of twist insertion during yarn production relies heavily on the tension of the bottom drafting apron. The main thing playing an important role is that fibres are stressed with higher force in case of slightly higher tensions which may cause the regular distribution of fibres per cross-section of the fibre strands reducing irregularities and fibre breakages and increasing strength properties. But the further increase of tension cause higher stretches applied to the fibres, which causes the breakage of the fibres, causing the increase of irregularities and hamper in the distribution of the fibres per cross-section and the strength of the fibre strands. The trend of results of the bottom apron tension position as well as the tension of the bottom apron indicates that the yarn properties and strength will decrease further if we increase the tension further. As we aim to obtain better yarn quality here, we don't prepare the yarns for positions 6 and 7. Effects of different qualities with the variation bottom apron tension are described as follows.

Effect of bottom apron tension variations on unevenness (%) and coefficient of variation (%) of produced yarn

The value of U% during different locations of tension positions 1, 2, 3, 4, and 5 of the bottom apron is shown by the average U% of the observed samples. Here, U % maintains a steady decrease up to position 3. But after position 3, the unevenness of the yarns starts to increase with the increase of bottom apron tension. The reason behind this is, firstly, the increase of apron tension enables better drafting and even distribution of the fibres, improving the evenness. Secondly, a further increase in tension causes further stretch on the fibres. Still, this time it causes negative phenomena such as the breakage of fibres. It reduces the fineness of the fibre strands, which is responsible for the irregular distribution of the fibres per cross-section of the yarns causing more irregularities. As we know that CV% is 1.25 times the U%, there will be the exact significance of CV% like U% of the yarn quality when varying the bottom apron tensions. For this reason, we have also considered U% in place of CV% in the case of ISM methodology.

Effect of bottom apron tension variations on IPI value of produced yarn

The same trend is observed in the case of the IPI value of the yarn, like yarn unevenness values. The reason is also mostly the same as the previous one with the increase of tension up to specific points, and better distribution of fibres and drafts achieved, which causes the decrease of the imperfection values. But after a specific tension increase, fibres will be applied more stretch, consequently increasing the amount of uncontrolled draft, causing higher imperfection values.

Effect of bottom apron tension variations on the hairiness of produced yarn

Low hairiness values are reflected by reducing bottom apron tension and maintaining the middle-ground positions. A yarn with a low hairiness value is of high quality of yarn. Because of the frictional force between the fibres, hairiness develops when the fibres separate from the surface of the yarn up to the increase of the tension at position 3, where the graph indicates the lowest value of hairiness because of containing the least amount of protruding fibres at the yarn surface. Due to factors such as high fibre friction, spindle speed, fibre characteristics, etc., the overall graphical result could have been more consistent at this position. But with further tension increase, the fibre breakage rate increases, which causes the increase of shorter uncontrolled fibres causing more hairy fibres at the yarn edge. With the higher increase of tension, the twist insertion is also disturbed. Because of those reasons, yarn hairiness also increases [33].

Effect of bottom apron tension variations on the hairiness of produced yarn

Up to position 3, the above three yarn quality increases, and with further tension increase, those three yarn qualities decrease. The same thing has also been observed for the count strength values of yarns. It is clear from the above table that as the bottom apron tension is decreased and the tension bar groove positions are shifted forward, the value of CSP drops. The CSP value is highest at position number 3, at 2743. Stepping down gradually while the position moves forward and the tension is released. With the exact yarn count, the yarn with a higher CSP performs better than the one with a lower CSP.

Key findings

With higher bottom apron tension and the tension's position at the midpoint, especially at position 3, the unevenness (Um), imperfection index (IPI), and Hairiness (H) values remain the lowest. Moreover, in this position, Count Strength Product (CSP) also shows the highest values, indicating better overall yarn quality. According to the experts, as the yarn will be used to produce knit products, CSP is considered the most suitable property for knit yarn [45,35].
From the ISM, it is also observed that Count Strength Product (CSP) is at the highest level, ensuring that it is the most influential quality characteristic for the produced yarns [46,47].

Limitations

This experiment is conducted only for the yarn count of 30 Ne, and due to unavailability, only 6 spindles of Ring Frame are used each time. Because of the absence of available technology, we cannot measure the bottom apron's tension values for each tension bar spring hole position. If it had been feasible to measure the tension value of the bottom apron, the evaluation would have been more straightforward. Another limitation of this research is that only ISM methodology prioritizes or ranks the produced ring spun yarn quality parameters. Furthermore, there is also another limitation which is the limited number of experts due to their busy schedules of them. According to the statistical analysis, the number is in the poor range. If we can manage more expert opinions, then the ISM calculation inputs would be more reliable [46].

Future scopes

- The effect of different tensions and lifetime of bottom aprons combinedly on the quality of this type of yarn can be further studied.
- The effect of different tensions of the bottom apron on the quality of cotton combed yarn or for different cotton blends can be studied further.
- Other Multicriteria Decision Making (MCDM) methodologies such as TISM (Total Interpretive Structural Modelling), FSE (Fuzzy Synthetic Evaluation), and Cause-Effect Diagram for finding the root cause analysis can be further studied in the future.

CONCLUSION

The profitability of any industry is based mainly on the acceptable quality of the end products. It also plays a more vital role when the end product of one industry is the initial raw material for many other industries' products; the quality of the finished product is mainly essential for the raw material quality.

The most important thing is that yarn is the first backward linkage of textile and clothing manufacturing. This study will hugely contribute to the following points:

First of all, different factories use different types of tension positions and tensions when producing their end product, such as yarn. Still, they do not even know the effect of those tensions on largely varying quality, even sometimes largely degrading the quality of the yarns and the subsequent products producing it. There is also a trend in the yarn quality with certain deviations at the starting and ending points, but at position 3, the best quality is achieved.

Secondly, prioritizing or ranking the quality parameters predominantly affects the quality of the produced yarns from the said four quality parameters using ISM methodologies. However, this methodology is relatively uncommon in this field.

Author Contributions

Conceptualisation – Raian S; methodology – Raian S; formal analysis – Raian S; investigation – Raian S; resources – Raian S; writing-original draft preparation – Raian S; editing – Akter S and Baral LM; visualisation – Akter S and Baral LM; supervision – Akter S and Baral LM. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

REFERENCES

[1] Soltani P, Shahrabi J, Asadi S, Hadavandi E, Johari MS. A study on siro, solo, compact, and conventional ring-spun yarns. Part III: modeling fiber migration using modular adaptive neuro-fuzzy inference system. The Journal of The Textile Institute. 2013; 104(7):755-765. https://doi.org/10.1080/00405000.2012.755295

[2] Raian S, Ali SM, Sarker MR, Sankaranarayanan B, Kabir G, Paul SK, Chakrabortty RK. Assessing sustainability risks in the supply chain of the textile industry under uncertainty. Resources, Conservation and Recycling. 2022; 177:105975. https://doi.org/10.1016/j.resconrec.2021.105975

[3] Raian S, Siddiqua T, Moktadir MA, Rahman T. An empirical model for identifying and controlling operational and environmental risks in spinning industry in an emerging economy. Computers & Industrial Engineering. 2023; 180:109244. https://doi.org/10.1016/j.cie.2023.109244

[4] Buharali G, Omeroglu S. Analiza porównawcza właściwości zgrzebnej przędzy bawełnianej wyprzędzionej konwencjonalnym i nowym zmodyfikowanym system obrączkowym. Fibres & Textiles in Eastern Europe. 2019; 27(2):45-51. https://doi.org/10.5604/01.3001.0012.9986

[5] Islam MI, Uddin AJ. Enhancing the quality of elastane-cotton core yarn by compact spinning. Heliyon. 2022; 8(6):09562. https://doi.org/10.1016/j.heliyon.2022.e09562

[6] Ying G, Jie F, Rong Y, Xungai W, Van Der Sluijs M, Xiaoming T. Investigation and evaluation on fine Upland cotton blend yarns made by the modified ring spinning system. Textile Research Journal. 2015; 85(13):1355-1366. https://doi.org/10.1177/0040517514563717

[7] Jabbar A, Palacios-Marín AV, Ghanbarzadeh A, Yang D, Tausif M. Impact of conventional and modified ring-spun yarn structures on the generation and release of fragmented fibers (microfibers) during abrasive wear and laundering. Textile Research Journal. 2023; 93(5-6):1099-1112. https://doi.org/10.1177/00405175221127709

[8] Liu X, Liu W, Zhang H, Su X. Research on pneumatic compact spun yarn quality. The Journal of The Textile Institute. 2015; 106(4):431-442. https://doi.org/10.1080/00405000.2014.925198

[9] Yu H, Yang S, Jiang W, Liu K, Jiang L, Chen J, Li Z, Xia Z, Xu W. The Influence of a Rotary Compact Groove Cylinder on the Properties of Ring Spun Yarn. Journal of Natural Fibers. 2023; 20(1):2172640. https://doi.org/10.1080/15440478.2023.2172640

[10] Soltani P, Vadood M, Johari MS. Modeling spun yarns migratory properties using artificial neural network. Fibers and Polymers. 2012; 13(9):1190. https://doi.org/10.1007/s12221-012-1190-9

[11] Srivastava RR, Singh PK. Selection of factors affecting integrated municipal wastewater treatment and reuse network: An interpretive structural modelling (ISM) approach. Environment, Development and Sustainability. 2022. https://doi.org/10.1007/s10668-022-02428-x

[12] Poduval PS, Pramod VR, VP JR. Interpretive structural modeling (ISM) and its application in analyzing factors inhibiting implementation of total productive maintenance (TPM). International Journal of Quality & Reliability Management. 2015; 32(3):308-331. https://doi.org/10.1108/IJQRM-06-2013-0090

[13] Sorooshian S, Tavana M, Ribeiro-Navarrete S. From classical interpretive structural modeling to total interpretive structural modeling and beyond: A half-century of business research. Journal of Business Research. 2023; 157:113642. https://doi.org/10.1016/j.jbusres.2022.113642

[14] Delhom CD, Kelly B, Bristow Martin V. Physical Properties of Cotton Fiber and Their Measurement. In: Fang DD, editor. Cotton Fiber: Physics, Chemistry and Biology. Manhattan, New York City: Springer International Publishing; 2018. p. 41–73. https://doi.org/10.1007/978-3-030-00871-0_3

[15] Farag R, Elmogahzy Y. 3 - Tensile properties of cotton fibers. In: Bunsell AR, editor. Handbook of Tensile Properties of Textile and Technical Fibres. Cambridge, UK: Woodhead Publishing; 2009. p. 51–72. https://doi.org/10.1533/9781845696801.1.51

[16] Mathangadeera RW, Hequet EF, Kelly B, Dever JK, Kelly CM. Importance of cotton fiber elongation in fiber processing. Industrial Crops and Products. 2020; 147:112217. https://doi.org/10.1016/j.indcrop.2020.112217

[17] Elmogahzy Y, Farag R. 7 - Tensile properties of cotton fibers: importance, research, and limitations. In: Bunsell AR, editor. Handbook of properties of textile and technical fibres. Cambridge, UK: Woodhead Publishing; 2018. p. 223-273. https://doi.org/10.1016/B978-0-08-101272-7.00007-9

[18] Kemp K, Griffiths J, Campbell S, Lovell K. An exploration of the follow-up up needs of patients with inflammatory bowel disease. Journal of Crohn's and Colitis. 2013; 7(9):386-395. https://doi.org/10.1016/j.crohns.2013.03.001

[19] Jiang W, Guo M, Gao W. Research on a novel sheath core-wrap staple yarn based on the ring spinning frame with special-shaped roller. Textile Research Journal. 2023. https://doi.org/10.1177/00405175231169291

[20] Quan J, He Q, Cheng L, Yu J, Xue W. Investigation into novel drafting systems on ring spinning frame for improving yarn properties. Textile Research Journal. 2022; 92(19-20):3413-4325. https://doi.org/10.1177/00405175211073824

[21] Cui Y, Cheng L, He S, Lyu J, Cui Y, Deng W. Comparative study of soft drafting system and the conventional drafting system based on the ring spinning frame. Textile Research Journal. 2022; 93(9-10):2330–2341. https://doi.org/10.1177/00405175221144773

[22] Quan J, Cheng L, Wang J, Xue W, Fang B. Mechanical analysis and numerical simulation of a multivariate principle curve draft device and analysis of its yarn properties. Textile Research Journal. 2020; 90(23-24):2648-2657. https://doi.org/10.1177/0040517520925503

[23] Quan J, Cheng L, Xue W, Zhang R. Comparative analysis of novel drafting devices and traditional roller drafting device in ring spinning on the acceleration point distribution and yarn properties. The Journal of The Textile Institute. 2021; 112(12):1965-1973. https://doi.org/10.1080/00405000.2020.1857092

[24] Li J, Zuo B, Wang C, Tu W. A direct measurement method of yarn evenness based on machine vision. Journal of Engineered Fibers and Fabrics. 2015; 10(4). https://doi.org/10.1177/155892501501000403

[25] Haleem N, Bustreo M, Del Bue A. A computer vision based online quality control system for textile yarns. Computers in Industry. 2021; 133:103550. https://doi.org/10.1016/j.compind.2021.103550

[26] Kulkarni KM, Sahu AR. Brief Overview on Study of Various Parameters Affecting the Productivity of Cotton Yarn. In: Lal Kolhe M, Jaju SB, Diagavane PM, editors. Smart Technologies for Energy, Environment and Sustainable Development, Vol 1: Select Proceedings of ICSTEESD 2020. 2022. p. 955-963.

[27] Walle GA, Atalie D, Tarekegn E, Wudneh A, Desalegn A. Prediction of mechanical, evenness and imperfection properties of 100% cotton ring spun yarns with different twist levels. Mehran University Research Journal of Engineering & Technology. 2022; 41(1):14-22. http://dx.doi.org/10.22581/muet1982.2201.02

[28] Sarioğlu E, Nohut S, Vuruşkan D, Yayla O. Production and characterization of recycled polyester (r-PET) blend vortex and ring spun yarns. The Journal of The Textile Institute. 2020; 111(12):1705-1712. https://doi.org/10.1080/00405000.2020.1720360

[29] Barella A. Yarn hairiness. Textile Progress. 1983; 13(1):1-57. https://doi.org/10.1080/00405168308688897

[30] Singh C, Gordon S, Wang X. The mechanism of hairiness reduction in offset ring spinning with a diagonal yarn path. Textile Research Journal. 2019; 89(8):1546-1556. https://doi.org/10.1177/0040517518775915

[31] Khan MR, Dip TM, Rashid ME, Ul Haque R, Kabir Neloy F, Minhajus Salehin SM, Galib S, Sayem ASM. Comparative Analysis of Production Processes and Quality Parameters of Two Different Semi-Combed Yarns. Journal of Natural Fibers. 2023; 20(1):2163333. https://doi.org/10.1080/15440478.2022.2163333

[32] Yang S, Gordon S. Accurate prediction of cotton ring-spun yarn quality from high-volume instrument and mill processing data. Textile Research Journal. 2017; 87(9):1025-1039. https://doi.org/10.1177/0040517516646051

[33] Ramaji IJ, Memari AM. Interpretation of structural analytical models from the coordination view in building information models. Automation in Construction. 2018; 90:117-133. https://doi.org/10.1016/j.autcon.2018.02.025

[34] Quan J, Cheng L, Yu J, Xue W. Numerical simulation of dynamic pressures on a novel drafting system and experimental study on yarn properties based on friction fields. Textile Research Journal. 2022; 92(7-8):999-1011. https://doi.org/10.1177/00405175211046059

[35] Erşahin HI, Korkmaz Y. The Effect of the Ring Spinning Machine Top Drafting Roller Hardness and the Fiber Blend Ratio on the Quality of Yarn. Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi. 2022; 5(3):1274-1281. https://doi.org/10.47495/okufbed.1037030

[36] Quan J, He Q, Cheng L, Yu J, Xue W. Finite element modeling and experimental investigation between the novel drafting and double-apron drafting systems. Textile Research Journal. 2022; 93(3-4):726-738. https://doi.org/10.1177/00405175221125250

[37] Sorooshian S, Tavana M, Ribeiro-Navarrete S. From classical interpretive structural modeling to total interpretive structural modeling and beyond: A half-century of business research. Journal of Business Research. 2023; 157:113642. https://doi.org/10.1016/j.jbusres.2022.113642

[38] Agrawal P, Narain R. Analysis of enablers for the digitalization of supply chain using an interpretive structural modelling approach. International Journal of Productivity and Performance Management. 2023; 72(2):410-439.

[39] Sindhwani R, Behl A, Sharma A, Gaur J. What makes micro, small, and medium enterprises not adopt Logistics 4.0? A systematic and structured approach using modified-total interpretive structural modelling. International Journal of Logistics Research and Applications. 2022. https://doi.org/10.1080/13675567.2022.2081672

[40] Singh S, Dhir S. Modified total interpretive structural modelling of innovation implementation antecedents. International Journal of Productivity and Performance Management. 2022; 71(4):1515-1536. https://doi.org/10.1108/IJPPM-05-2020-0239

[41] Raj A, Samuel C. Application of total interpretive structural modeling (TISM) for analysis of barriers influencing healthcare waste management sector: A case study. International Journal of Healthcare Management. 2022. https://doi.org/10.1080/20479700.2022.2114734

[42] Bakhtari AR, Waris MM, Sanin C, Szczerbicki E. Evaluating Industry 4.0 implementation challenges using interpretive structural modeling and fuzzy analytic hierarchy process. Cybernetics and Systems. 2021; 52(5):350-378. https://doi.org/10.1080/01969722.2020.1871226

[43] Guan L, Abbasi A, Ryan MJ. Analyzing green building project risk interdependencies using Interpretive Structural Modeling. Journal of Cleaner Production. 2020; 256:120372. https://doi.org/10.1016/j.jclepro.2020.120372

[44] Pitchaimuthu S, Thakkar JJ, Gopal PRC. Modelling of risk factors for defence aircraft industry using interpretive structural modelling, interpretive ranking process and system dynamics. Measuring Business Excellence. 2019; 23(3):217-239. https://doi.org/10.1108/MBE-05-2018-0028

[45] van Velzen JH. Students' general knowledge of the learning process: A mixed methods study illustrating integrated data collection and data consolidation. Journal of Mixed Methods Research. 2018; 12(2):182-203. https://doi.org/10.1177/1558689816651792

[46] Braun V, Clarke V. To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis and sample-size rationales. Qualitative Research In Sport, Exercise and Health. 2021; 13(2):201-216. https://doi.org/10.1080/2159676X.2019.1704846

[47] Faysal GM, Azad TNS, Repon MR, Hossain MT, Jalil MA. Sustainable yarn production using leftover fabric from apparel industries. Heliyon. 2022; 8(11):e11377. https://doi.org/10.1016/j.heliyon.2022.e11377