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The Main Barriers to the Implementation of Industry 4.0 in RMG for Bangladesh: A Fuzzy-AHP Analysis

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ABSTRACT: The manufacturing and processing industries in Bangladesh are being influenced by the Fourth Industrial Revolution. The goal of the study is to use the Fuzzy Analytical Hierarchy Process (Fuzzy-AHP) geometric mean approach, a Multi Criteria Decision Making (MCDM) methodology, to identify, analyze, and rank the main barriers to Industry 4.0 implementation in Bangladesh's Ready-Made Garments (RMG) industries. Using pairwise comparisons, the linguistic and numerical preferences of 11 specialists from various industries were collected. The four primary barriers identified from related review studies are used as input variables in the Fuzzy-AHP method to measure the intensity level of barriers. The results have shown that the main four barriers to Industry 4.0 are: Lack of Decision makers' support and industry owners' willingness (43%); Lack of Ability to cover digital infrastructure costs (29.3%); Lack of Technical skills and learning (17.5%); and Availability of a cheaper workforce (10.2%). The barriers are evaluated and prioritized based on their weightings, which measure the intensity of the barriers to Industry 4.0 implementation. Applying the consistency ratio verification technique, the collected ratio scales are validated.

Keywords - Industry 4.0; Fuzzy-AHP; Ready Made Garments (RMG); Main barriers; Pair wise Comparisons.

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1. INTRODUCTION

1.1 Background

The use of sustainable technology is opening new doors for economic development. The leading export-oriented companies in Bangladesh have developed over the years with decades of expertise to become the major (core) and generational businesses of the Bangladeshi people. The country's economy will be more receptive to the development of other industries in Bangladesh if a handful of high-quality products can succeed on the international market with the application of Industry 4.0. As a result, there is no choice but to continue with pleasant quality products that have already occupied a portion of the global market. Bangladesh's RMG industry produces high-quality garments using semi-automated and automated technologies and is eager to transition to Industry 4.0 as soon as possible. It is obvious that the company needs to create a business-friendly environment by removing barriers.

Industry 4.0 paves the way for new technology, particularly the digitization of products and business models, according to Dr. Reinhard et al.'s research [1]. The significant acceleration of change's velocity with smart manufacturing is the distinctive characteristic of digital transformation. Software, which comprises excellent sensor technology, digital networking, and data production, is taking centre stage in the product segment. Massive data exercise and integrated solutions' fundamental intelligences encourage new businesses to enter already-established markets, and the advantage of modern technology is that it removes conventional market entrance barriers. Big data and analytics, the internet of things, cyber-physical systems, smart factories, artificial intelligence, cloud computing, and block chain are some of the technology components of Industry 4.0 [2]. Ângelo et al. [3], shortens the time it takes to distribute high-quality goods around the world, offers sufficient adaptive product lines, boosts productivity, effectively uses resources, and incorporates the virtual global industry into global value chains. According to Fettig et al. [4], even if the effects of new technology might not be felt right away, they will show up in changes to the way people interact, work, do business, and live in both developing and developed nations. It is a good time for the Bangladeshi government,policymakers, industry experts, and business owners to take the necessary actions to launch Industry 4.0 in the manufacturing and service industries in order to take advantage of the opportunities offered by Industry 4.0, according to M. A. Islam et al. in [5]. The implementation of Industry 4.0 technologies that offer enormous facilities for industries with huge investments was recommended by Moktadir et al. [6] in their conclusion. Bangladesh has built over 8000 digital centres across the nation, according to Hossain et al., to instruct young people interested in science in a variety of digital categories [7, 8]. According to Dr. Abul Bashar et al. [9], there are several barriers that must be overcome before Industry 4.0 can be implemented in Bangladesh, despite the fact that there is a great deal of potential for doing so. As a result, the government, policymakers, and industrial groups must work together.

The purpose of this study is to identify the barriers through relevant review studies for Industry 4.0 application in RMG industries in Bangladesh. The research also aims to develop a mathematical model for analyzing and measuring the intensity level of barriers by applying the fuzzy-AHP geometric mean approach with triangular fuzzy numbers (TFNs) based on RMG industry experts' opinions. The study also aims to discuss strategies to overcome the intensity of hurdles in RMG for Industry 4.0 initiation in Bangladesh.

1.2 Literature Review

The RMG sector has emerged as one of Bangladesh's economic pillars, contributing significantly to export revenue. The industry got its beginnings in the late 1970s, and since then it has contributed significantly to the expansion of the economy and grown to become the main source of export revenue for the nation. While Bangladesh's industries are growing quickly, the ready-made garment (RMG) industry faces significant obstacles in implementing Industry 4.0. As a result, the government is driven to address these barriers and bring about significant changes in industrial production through the use of digital technology. Implementing Industry 4.0 in SMEs, Guido Orzes et al. [10] categorized the issues as being related to the implementation process, the legal system, technology, cultural norms, competences, and resources. M. A. Islam et al. [5] evaluated the expert opinions using a phenomenology design and identified a number of obstacles to implementing Industry 4.0 in Bangladesh, including inadequate infrastructure, a lack of less expensive labour, expensive technology installation, a lack of government support, and a lack of knowledge. Jabbour et al. [11] emphasized the advantages of putting Industry 4.0 into practice in Bangladesh, but they were also concerned about the drawbacks, such as a lack of knowledge, worker skill gaps, poor manufacturing infrastructure, a lack of investment, production-related technological applications, and so on. Hasan and Mahmud [12] considered several risks in their research, including finance/capital risk, insufficient employee qualifications, employee turnover risk, standards, regulations, militancy risk, building collapse risk, fire incident risk, labour unrest risk, political unrest risk, climate change risk, health and safety risk, sexual harassment risk, local politics risk, and administration risk.

The Industrial Internet, also known as Industry 4.0, is thought to have certain barriers but also has several essential capabilities, according to Dr. Reinhard Geissbauer et al. in [1]. High investment levels and frequently ambiguous business reasons for new technology applications are the key points of attention. It is urged that each organization analyze its current Industry 4.0 competencies and set its digitization objectives. They also identified "lack of support by top ma nagement" as one of the main issues. Thus, attempts to speed the system as a whole can be aided by legislators and commercial entities.

The aforementioned discussions and literature study make it clear that, as a new technical adaption, Industry 4.0 implementation in the RMG sector may run into some major variable barriers. As noted below, barriers could appear in the context of Bangladesh:

(1) Lack of Decision makers' support and industry owners' willingness, (Criteria B1)
(2) Lack of Technical skills and learning regarding Industry 4.0, (Criteria B2)
(3) Lack of Ability to cover digital infrastructure costs, (Criteria B3) and
(4) and Availability of a cheaper workforce, (Criteria B4)

The majority of the studies in the foregoing literatures are review studies that concentrate mainly on various barriers for Industry 4.0 application. In this study, four main barriers identified above are taken into account as input variables in the methodology of fuzzy-based mathematical model, which was created to quantify the level of intensity of challenges facing RMG in Bangladesh.

1.3 Objectives

The research objectives are as follows:

- To evaluate the main obstacles of Ready-Made Garments (RMG) in an Industry 4.0 application from the related review studies for Bangladesh.
- To develop a questionnaire for pair-wise comparison among the main barriers and to collect experiences on both a linguistic and numeric scale from the RMG industry experts.
- To create a Fuzzy-AHP analysis mathematical model based on pair-wise data collected from RMG experts and prioritization of major obstacles, as well as to mention techniques to address the challenges for Industry 4.0 application in Bangladesh.

1.4 Research Methodology

Implementing Industry 4.0 is regarded as a fuzzy decision-making problem, which is analogous to human perception and a good outcome for multi-criteria decision-making procedures. The fuzzy decision-making approach aids in dealing with a formal methodology for representing and implementing human experience-based uncertain judgments in situations where a traditional mathematical formulation of the problem is impossible or extremely difficult due to many ambiguities, large uncertain business environmental obstacles, etc. The intensity of barriers to the implementation of Industry 4.0 at RMG in Bangladesh is measured in this study using Fuzzy Analytical Hierarchy Processes (Fuzzy-AHP) with Triangular Fuzzy Numbers (TFNs), which can handle a wide range of uncertainties and computation simplicities. The research used the RMG's business environment barriers (which were identified through review studies) as input variables in the methodology to develop a fuzzy mathematical model. A questionnaire for pairwise comparisons among the criteria was developed to share knowledge and experience and collect data from industry-related specialists. A verification technique is used to calculate the consistency ratio (CR) for the validation of ratio scales collected from industry experts.

1.5 Flow Chart of Research Methodology

A flowchart in Fig. 1 is presented here to show the various steps of the research process model in a sequential manner.

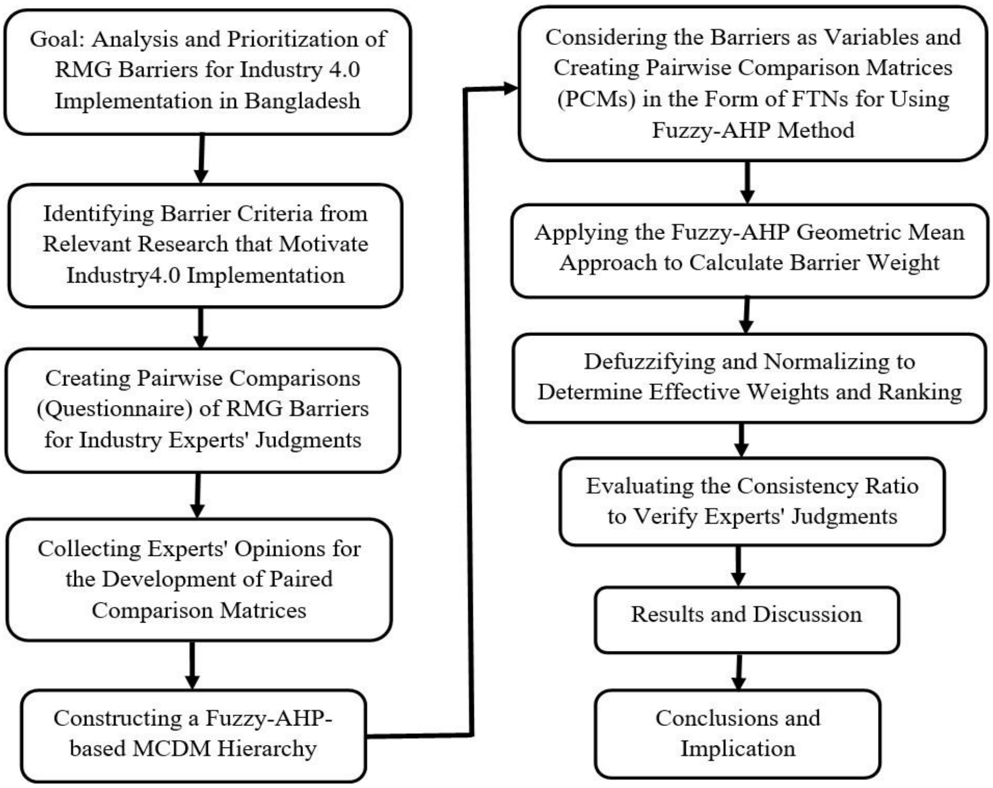

Figure 1. Flow Chart of the research methodology

2. MATERIAL AND METHODS

2.1 Creation of Pair-wise Comparisons and Questionnaire

The n by n matrix A = [a_{ij}] designates a pair-wise comparison matrix, where $a_{ij} > 0$. The term a_{ij} is frequently used to refer to an expert's comparison assessment of one criterion against another. The relative scale (from 1 to 9) is used to assign grades to each paired comparison. According to Saaty T. L. in [13], a scale of 1 represents the pairwise comparison's lowest score or equal weight, while a scale of 9 represents the pairwise comparison's highest score.

A pair-wise comparison with a questionnaire is used in Tables 1 and 2 for collecting verbal and numerical industry expert opinions. Here is a survey questionnaire with one set of evaluations for a single expert over six pairwise comparisons.

Question 1: Which challenge is more lacking, especially in your Ready-Made Garments factory, between "Technical Skills & Learning" (Criteria B2) and "Decision makers' support and industry owners' willingness" (Criteria B1) for Industry 4.0 implementation, and to what extent? Please include (√) the crisp value based on linguistic terms and the relative scale (RS) of your expertise.

Table 1. Evaluation of Expert-1 for this comparison

Technical Skills & Learning, B2								1	Decision Makers' Support & Owners' Willingness, B1							
9	8	7	6	5	4	3	2		2	3	4	5	6	7	8	9
						⅓				√						

Table 2. Scale of relative importance

Crisp Numeric Value	Linguistic Variable
1	Equally importance
3	Moderately importa
5	Strongly importance
7	Very strongly impo
9	Extremely importan
2, 4, 6, 8	Intermediate values importance
1/3, 1/5, 1/7, 1/9	Values for recipro comparisons

2.2 Mathematical Representation

2.2.1 Fuzzy Set Theory

Lotfi A. Zadeh, in the beginning, introduced a mathematical analysis of imprecision as a Fuzzy set in 1965. A fuzzy set whose membership function satisfies the normality and convexity requirements is the definition ofa fuzzy number. It uses membership functions ranging from zero to one to represent an object's membershipin a crisp numerical collection.

In a discrete and finite universe of discourse *X,* a fuzzy set $\widetilde{A}$ is defined as:

$$\tilde{A}=\mu_{\tilde{A}}(x_1)/x_1 + \mu_{\tilde{A}}(x_2)/x_2 + ------=\sum_X \mu_{\tilde{A}}(x_i)/x_i = \{(x_i, \mu_{\tilde{A}}(x_i)) \mid x_i \in X\} \quad (1)$$

Where, $x_1, x_2, x_3, -, -, -, -$ are the elements of *X* and $\mu_{\tilde{A}}$: *X* → [0, 1] is called membership function $\mu_{\tilde{A}}(x_i)/x_i$

The complement of a fuzzy set A is a fuzzy set $\widetilde{A}$ in the universe of discourse *X* and its membership function is defined as:

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x) \ \forall \ x \in X \quad (2)$$

2.2.2 Fuzzy Set Theory

A fuzzy set $\tilde{A}$ is convex if and only if for any x_1 $x_2 \in X$ and any parameter lambda, $\lambda \in [0,1]$, the following condition (as shown in Eq. (3) of the membership function of $\widetilde{A}$ satisfies the inequality:

$$\lambda_{\tilde{A}}\{\lambda x_1 + (1-\lambda)x_2\} \geq \min\{\mu_{\tilde{A}}(x_1), \ \mu_{\tilde{A}}(x_2)\}; 0 \geq \lambda \leq 1 \quad (3)$$

Where min stands for the minimum operator. As demonstrated in Fig. 3, the intersection of two convex fuzzy sets is also convex.

2.2.3 Height of a fuzzy set

The membership function's maximum value is the height of a fuzzy set $\tilde{A}$. The height of a fuzzy set $\tilde{A}$ is formulated in Eq. (4):

$$hgt(\tilde{A}) := sup_{x \in X} \mu_{\tilde{A}}(x) \quad (4)$$

2.2.4 Normal Fuzzy Set

A fuzzy set $\widetilde{A}$ is normal if its core is non empty that is at least a point *x* in *X* such that $\mu_{\tilde{A}}(x) = 1$. The conditioned of un-normal fuzzy set $\tilde{A}$ of which the basic set is nonempty is defined as:

$$0 < hgt(\tilde{A}) < 1$$

Normalization of a nonempty/subnormal fuzzy set $\tilde{A}$ is always possible by division of $\mu_{\tilde{A}}(x)$ by $sup_{x \in X} \mu_{\tilde{A}}(x)$ for all $x \in X$. The equation of normalized fuzzy set A' is defined by the Eq. (5):

$$A' = Norm(\tilde{A}) = \sum \frac{\mu_{\tilde{A}}(x)}{hgt(\tilde{A})} / x \quad (5)$$

2.2.5 Support of a fuzzy set

The support of a fuzzy set $\tilde{A}$ for any associated membership function such that $\mu_{\tilde{A}}(x) > 0$ can be represented as shown in Eq. (6):

$$supp(\tilde{A}) := \{x \in X \mid \mu_{\tilde{A}}(x) > 0\} \quad (6)$$

It is called support of $\tilde{A}$.

2.2.6 Triangular fuzzy number (TFNs)

In [14], Chang proposed the triangular fuzzy membership function for the pairwise comparison judgment matrix. In this study, the researchers used triangular fuzzy numbers because they are more approachable and easier to utilize. TFNs are represented by [*l m u*] (as shown in Figs. 2 and 3 and the membership function μ_M is defined as follows.

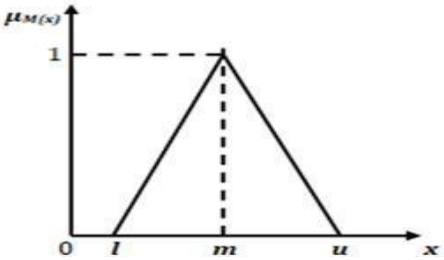

Figure 2. Membership functions of Fuzzy Triangular Number

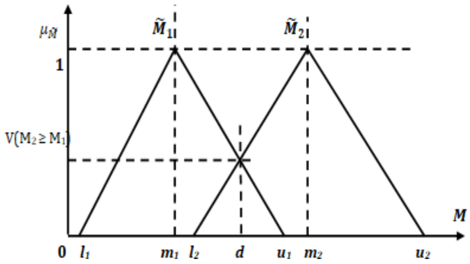

Figure 3. Intersection between TFNs [15]

The symbol for a triangular fuzzy number is $\widetilde{M} = (l, m, u)$ as shown in Fig. 2, where l, m, u are real numbers and $l < m < u$. The membership function $\mu_{\widetilde{M}}(x)$ can be described by the following equation:

$$\mu_{\widetilde{M}}(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in [l, m], \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

2.2.7 Defuzzification

To obtain a crisp value, the output fuzzy set must be defuzzified. The center of gravity (COG) defuzzification method is used in the Mamdani inference strategy. Under the fuzzy set *B'*, this technique computes the *y* coordinate of the area's center of gravity as shown in Eq. (8):

$$y' = \text{cog}(B') = \frac{\sum_{j=1}^{F} \mu_{B'}(y_j) y_j}{\sum_{j=1}^{F} \mu_{B'}(y_j)} \quad (8)$$

Where, *F* is the number of elements y_j in *Y*.

2.2.8 Consistency Index and Consistency Ratio

A decision-making complex problem requires the adaption of expert verbal and numerical experiences, as well as consistency testing. To authenticate the experts' opinions, the Analytical Hierarchy Process fundamentally depends on the Consistency Ratio (CR). The AHP approach computes ratio scales based on paired comparisons of criteria and allows for minor inconsistencies in assessments. The permissible CR is less than 10%, indicating that the weights are acceptable. Otherwise, the expert's recommendation should be changed or rejected. The consistency ratio is calculated using the equation below (CR):

$$Consistency\ Rayio, CR = \frac{Consistecy\ Index\ (CI)}{Random\ Index\ (RI)} \quad (9)$$

Here, CI = Consistency Index, the largest Eigen value (λ_{max}) of matrix of order n

$$Consistency\ Index, CI = \frac{Largest\ Eigen\ Value - n}{n-1} = \frac{\lambda_{max} - n}{n-1}$$

The 'n' stands for the number of requirements. The Random Index (RI), whose value is obtained from the RI standard table, is the consistency index of a pairwise matrix generated at random.

2.2.9 Fuzzy Analytical Hierarchy Process (FAHP)

The traditional AHP technique is an excellent option for multi-criteria decision making because it is similarto human judgment. Using the AHP technique, independent assessments are transformed into ratio scale weights for successful paired comparison and ranking of choice criteria. The fundamental bestowals of AHP include pairwise comparisons, uncertain judgments, an eigenvector approach for calculating weights, and consistency criteria. But the AHP technique is insufficient for considering cognitive aspects of human experiences. So, the traditional AHP method for determining criteria ratio scale weights does not provide sufficient accuracy. Fuzzy-AHP is a development of Saaty's theory [16] that overcomes the ambiguity/uncertainty of the AHP approach. In [17], Kilincci O. and Onal S. A. concluded that the Fuzzy-AHP technique deals with more uncertain opinions, both in linguistic terms and on a relative scale, and that it takes into account a set of values (TFNs) to cover the ambiguity where the prioritization of criteria will be more assured. The classical AHP method, on the other hand, simply works with a single weighted value of criterion. The linguistic term or variable, along with a scale of its relative importance and a triangular fuzzy scale for criterion, are illustrated in Table 3 below. The Fuzzy-AHP geometric mean method with TFNs and expert input, as described in Saaty T. L.'s study [18], yields better outcomes. A hierarchy with the main purpose or objective of the problem, criteria, sub-criteria, and alternative levels must be built in order to improve decision-making. In [19], Sharma and Yu made the decision that all the components would be compared in pairs in order to determine their relative relevance at both this level and the level above. The system computes eigenvectors up till the composite final vector is produced. The final weighting vector shows how much each criterion is weighted in relation to the main goal. Only the objective, criteria for selection, and results of hierarchy are taken into consideration in this study.

2.2.10 Fuzzy Conversion Weight Scaling

Due to its broad range of values, fuzzy-AHP provides decision makers with a more reliable way for handling uncertainty. Table 3 shows a relationship between a language opinion, a precise numerical value, and TFNs. This relationship is known as fuzzy fundamental scaling. This procedure is carried out by performing a pairwise comparison with the aid of Table 3 [20], assigning a full number to the criterion that is more important and a reciprocal assessment for the criterion of least relevance.

Table 3. Fuzzy conversion scale from crisp numeric relative scale

Linguistic variable scale/terms	Crisp numeric relative scale	Triangular fuzzy number	Reciprocal Triangularfuzzy number
Equally important	1	(1, 1, 1)	(1/1, 1/1, 1/1)
Judgment value between equally and moderately	2	(1, 2, 3)	(1/3, 1/2, 1/1)
Moderately more important	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Judgment value between moderately and strongly	4	(3, 4, 5)	(1/5, 1/4, 1/3)
Strongly more important	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Judgment value between stronglyand very strongly	6	(5, 6, 7)	(1/7, 1/6, 1/5)

Very strongly more important	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Judgment value between very strongly and extremely	8	(7, 8, 9)	(1/9, 1/8, 1/7)
Extremely more important	9	(9, 9, 9)	(1/9, 1/9, 1/9)

2.2.11 Fuzzy Geometric Mean and Synthetic Equations

TFN can express the fuzzy judgment matrix $\tilde{A}(a_{ij})$ mathematically using pairwise comparison. Divergent opinions on the same criterion may be presented by different specialists. The Fuzzy-AHP geometric mean approach is used to aggregate the several given judgments into one fuzzy figure for each criterion. The following formula shown in Eq. (10) can be used to calculate the geometric mean:

Geometric mean = $\{(x_1)\ (x_2)\ (x_3)\ ....\ (x_n)\}^{1/n}$ (10)

Where, x = individual paired weight value of individual expert

n = Sample size (number of judgment)

Consider a fuzzy triangular number $A = a_{ij}$ is written as $[l_{ij}, m_{ij}, u_{ij}]$, i and j = 1, 2, -, -, -, n, where l_{ij}, m_{ij}, u_{ij} are the lower bound, middle bound and upper bound of the triangular fuzzy set. Also, assume that $l_{ij}<m_{ij}<u_{ij}$, when $i \neq j$.

$$a_{ij}=[l_{ij}, m_{ij}, u_{ij}]$$
$$a_{ij}^{-1}=[\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}]$$

If $i = j$, then $a_{ij} = a_{ii} = (1, 1, 1)$. As a result, the judgment matrix produces an accurate priority vector $w = (w_1, w_2, --, --, --, w_n)$, which must address inequality. The following formula (as shown in Eq. 11) was published by Chang et al. (1996) to determine the synthetic value:

$$a_{ij}^{t} = [a_{ij}^{t}, a_{ij}^{t}, a_{ij}^{t}], i, j = 1, 2 - --, n_k;\ \ t = 1, 2 \quad (11)$$

'T' is a TFN given by the tth expert, by the formula kth as shown in Eq. (12):

$$M_{ij}^{k} = \frac{1}{\tau} \otimes (a_{ij}^{1} + a_{ij}^{2} + \cdots + a_{ij}^{\tau}) \quad (12)$$

Using the fuzzy comparison matrix theory, the following formula shown in Eq. (13) can be used to determine the value of fuzzy synthetic extent in relation to the i_{th} item:

$$S_j^k = \sum_{j=1}^{n} M_{ij}^{k} \otimes \left[\sum_{i=1}^{n_k} \sum_{j=1}^{n_k} M_{ij}^{k}\right]^{-1}, i, j = 1, 2, ---, \quad (13)$$

3. Mathematical Calculations

3.1 Criteria Weight Calculation for Obstacles

For computing the criteria weight value for barriers to ready-made garments in Bangladesh's Industry 4.0 application, the study developed a Fuzzy-AHP geometric mean approach. The review study and expert opinions highlight the key barriers/challenges the RMG sector is facing in implementing Industry 4.0.

Then, consider matrices for single-value pair-wise comparison for the four key RMG barriers are generated utilizing industry executives' verbal judgments based on the above questionnaire Table 2 (pairwise comparisons) and its relative relevance crisp numeric value. In the Fuzzy-AHP geometric mean method, these numbers are turned into triangular fuzzy numbers (TFNs). The Fuzzy-AHP method is a participation and data-oriented analysis system in the MCDM approach. Expert opinions or pair-wise judgments were collected from 11 executives of three Bangladeshi ready-made garment firms. The interviews were conducted initially with 13 experts. Two of the thirteen ratio scales provided were inconsistent. As a result, 11 executives made effective/consistent decisions, which were incorporated into the study's methodology by eliminating two inconsistent opinions. The professionals' backgrounds encompassed operations and production management, quality assurance managers, business development executives, engineering and design, and other areas. Each member of the team has a wide range of expertise in their specialized professions. The collected vocal phrases (opinions) and their relative scale are used to create pairwise comparison single-value matrices for 11 experts.

Table 4 shows two paired comparisons (Expert-1 and Expert-2) out of 11 pairwise comparison matrices.

Table 4. Experts' Evaluations for Paired Comparisons

Judgment of Expert-1						Judgment of Expert-2				
Barriers as Criteria	DMS, B1	TSL, B2	ACDI Cost, B3	ACW, B4		Barriers as Criteria	DMS, B1	TSL, B2	ACDI Cost, B3	ACW, B4
DMS, B1	1	3	1	4		DMS, B1	1	2	2	4
TSL, B2	1/3.	1	1/2.	2		TSL, B2	1/2.	1	1/2.	2
ACDI Cost, B3	1/1.	2	1	3		ACDI Cost, B3	1/2.	2	1	3
ACW, B4	1/4.	1/2.	1/3.	1		ACW, B4	1/4.	1/2.	1/3.	1

Table 5 combines the 11 experts' judgments on each pair of comparisons into a single matrix, along with the number of experts who made that set of observations. All the 11 experts' judgments are illustrated in single value pairwise comparison matrices as given below in Table 5:

Table 5. Experts' opinions on the basis of linguistic terms and its relative importance scale

Relative scale Comparing ⟹ Criteria ⇩	Extremely Strong 9	Very Very Strong 8	Very Strong7	Strong Plus 6	Strong 5	Moderate plus 4	Mode rate 3	Weak Advantage 2	Equal 1
Barrier B1	0	0	0	0	0	0	9	2	0
Barrier B1	0	0	0	0	0	0	1	6	4
Barrier B1	0	0	0	0	4	6	1	0	0
Barrier B2	0	0	0	0	0	0	0	11	0
Barrier B3	0	0	0	0	0	0	1	9	1
Barrier B3	0	0	0	0	0	2	7	2	0
Reciprocal Re. Scale	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1/1

The remaining portion of the Table 5 (Continuation) with reciprocal relative scale is given below

Weak Advantage 1/2	Moder ate 1/3	Moderate plus 1/4	Strong 1/5	Strong Plus 1/6	Very Strong 1/7	Very Very Strong 1/8	Extremely Strong 1/9	With respect to	Total No. of Experts
0	0	0	0	0	0	0	0	B2	11
0	0	0	0	0	0	0	0	B3	11
0	0	0	0	0	0	0	0	B4	11
0	0	0	0	0	0	0	0	B4	11
0	0	0	0	0	0	0	0	B2	11
0	0	0	0	0	0	0	0	B4	11
2	3	4	5	6	7	8	9		

There are six paired comparisons produced based on the experts' assessments and the four primary criteria for barriers, such as Criteria B1 over Criteria B2, B1 over B3, B1 over B4, B2 over B4, B3 over B2, and B3 over B4. These measures are counted from left criteria with respect to right criteria, that is, right side criteria are comparing criteria in these judgments. When the same paired comparisons are considered in opposite directions, the measures are counted from the right criteria of the same Table 5 (right over left), and six new paired comparisons are obtained, with the values having to be the reciprocal of the previous six paired comparisons.

The given judgments of 11 experts for the comparison of "Criteria B1 with respect to Criteria B3" in Table 5 are explained in such a way that:

- Criteria B1 is equally important to Criteria B3 according to four experts, and its weight value is 1.
- Six experts agreed that a criterion B1 has a marginal advantage over criteria B3, and its weight value is 2.
- Criteria B1 is moderately important over B3 according to one expert, and its weight value is 3.

Similar explanations can be given for additional pairwise comparisons for 11 experts in a single-value matrix.

The layouts in Table 5 have now been transformed into a Fuzzy Triangular Number value (*l m u*) with the help of the conversion scale in Table 1 for applying Fuzzy-AHP geometric mean method in another table, which is not shown here due to a long table in an Excel sheet. The pairwise fuzzy triangular matrix for 11 experts was then converted to a non-normalized fuzzy triangular 4×4 pairwise matrix as stated in Table 6 using the geometric mean approach with geometric mean Eq. (10), where "*n*" represents the number of specialists.

For the four hurdles criteria, 4×4 matrix is created, and there are 16 elements in the matrix. Due to the comparison of one criterion with the same criterion, the scale value of the four diagonal elements is 1. The scale values of 6 pairwise comparisons are obtained from experts' judgments, and the rest of the 6 pairwise comparisons' weight values are accordingly reciprocal to those six pair-wise comparison values. For instance, in Table 6, the fuzzy pair-wise comparison values of B1 w. r. t. B2 (1.76318251, 2.786792687, 3.796154) and B2 w. r. t. B1 (0.26342449, 0.35883545, 0.56715626) are calculated for each element individually from Fuzzy-AHP geometric mean method, but according to the judgment, these two sets of fuzzy values are reciprocal with each other. The fuzzy value B2 w. r. t. B1 is found to be the reciprocal of B1 w. r. t. B2 after calculation. Therefore, it is reasonable to conclude that the calculation procedure is carried out in accordance.

Table 6. Fuzzy triangular pairwise matrix obtained by Fuzzy-AHP geometric mean method

Barriers	Criteria B1			Criteria B2			Criteria B3			Criteria B4		
Criteria B1	1	1	1	1.76318	2.78679	3.79615	1.06504	1.61277	2.06529	3.21030	4.22612	5.23544
Criteria B2	0.26342	0.35884	0.56716	1	1	1	0.35884	0.51325	0.93893	1.00000	2.00000	3.00000
Criteria B3	0.48419	0.62005	0.93893	1.06504	1.94837	2.78679	1	1	1	1.89808	2.93644	3.95334
Criteria B4	0.19101	0.23662	0.31150	0.33333	0.50000	1.00000	0.25295	0.34055	0.52685	1	1	1
TFNs	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*

Following (shown in Table 7) are the remaining mathematical methods for figuring out the % weight values of barriers at RMG in the Industry 4.0 application. The row-wise Fuzzy geometric mean value is represented in Table 7 as matrix A1, and each element from the aforementioned fuzzy triangular matrix is assessed using Eq. (10), where '*n*' represents the number of criteria for barriers. Matrix A2 is the column-wise sum of matrix A1, and the fuzzy synthetic weight of each criterion is calculated using fuzzy synthetic Eq. (13). In the defuzzification procedure, the center of the area of a fuzzy triangular matrix in Eq. (8), which is the arithmetic mean of TFNs, is employed. So as a result, the defuzzified weight Wi is calculated using the average value of TFNs. Defuzzified crisp numeric weights W_i for all criteria are added up, but the result does not equal 1. As a result, by dividing each weight vector by the sum, the non-fuzzy numeric weight vectors are normalized. The ranks of barriers and their normalized weights are derived in Table 7.

Table 7. Calculation of row wise geometric mean, fuzzy weights, de-fuzzified weights and normalized weightsof criteria

Row wise Fuzzy Geometric Mean $\widetilde{r}_i$ = A1			Fuzzy Weight of each Criteria $\widetilde{W}_i$ = (A1*(1/A2))			De-fuzzified Crisp Numeric Weights W_i	Normalized Weight of Criteria	Ranking
1.56694	2.08764	2.53116	0.25750	0.44540	0.72895	0.477283	0.430875	1
0.55448	0.77905	1.12425	0.09112	0.16621	0.32378	0.193702	0.174867	3
0.99466	1.37240	1.79339	0.16345	0.29280	0.51648	0.324246	0.292718	2
0.35624	0.44802	0.63648	0.05854	0.09559	0.18330	0.112476	0.101540	4
Column Wise Sum (A2) =								
3.47232	4.68711	6.08529	*l*	*m*	*u*	Sum = 1.107707	Sum = 1	

Fuzzy-AHP geometric mean is used to determine the row-wise fuzzy geometric mean value, fuzzy weights for each criterion, defuzzified crisp weights, and lastly normalized weights for criteria, as shown in Table 7. The degree of difficulty of barriers is indicated by these normalized weights, which are applied in subsequent calculations, findings, and discussions.

The normalized weights for each criterion and their middle bound value (*m)* are shown in parallel in Table 8 below. The fuzzy mid-bound value is also an effective method for comparison with normalized weightings and for further calculations.

Table 8. Normalized weights of criteria for obstacles, Fuzzy middle bound value and ranking of criteria

Barriers of RMG Sector for Industry 4.0 Implementation	Middle bound value (*m*) of Fuzzy Weights (W_i)	Normalized Weights of Criteria for Obstacles	Ranking
Lack of Decision makers' support and industry owners' willingness, (CriteriaB1)	0.445400	0.430875	1
Lack of Technical skills and learning, (Criteria B2)	0.166211	0.174867	3
Lack of Ability to cover digital infrastructure costs, (Criteria B3)	0.292803	0.292718	2
Availability of a cheaper workforce, (Criteria B4)	0.095587	0.101540	4

Fig. 4 shows a graphical representation of the normalized crisp weights and fuzzy middle bound value (*m*) of the barriers to the adoption of Industry 4.0 in Bangladesh's RMG sector. The mean bound value (*m*) of fuzzy synthetic weight for barrier B1 has the greatest lacking value of 0.4454, whereas the normalized weight value has the highest priority but the weighting is 0.430875. Additionally, there were variations on the second, third, and fourth hurdles, and the normalized % values of criteria B2 and B4 were marginally higher. The normalized weight values of the existing prioritized barriers can be provided for analysis, discussion, and further decision-making calculations because the Fuzzy-AHP technique always captures more ambiguity in its appreciations. On the other side, the fuzzy mean bound value (m) is quite similar to a single-choice application weight that disregards judgment ambiguity.

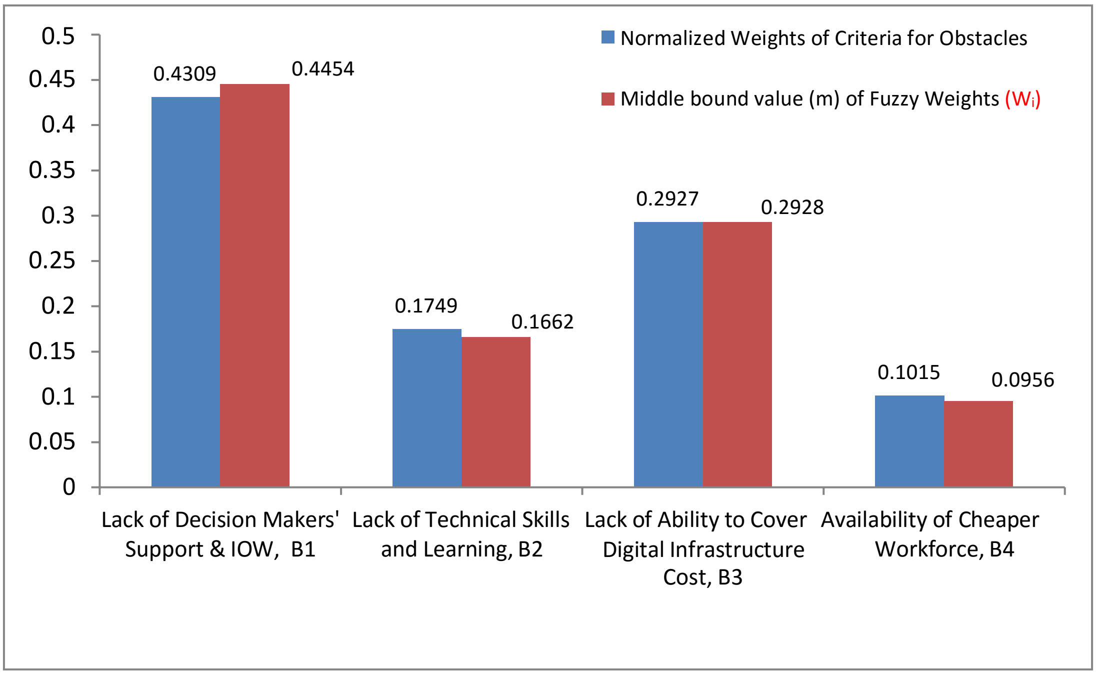

Figure 4. Criteria for Obstacles of RMG Sector in Industry 4.0 Implementation

3.2 Consistency Index (CI) and Consistency Ratio (CR) Calculation

The matrix given in Table 9 is the pairwise single value matrix that was obtained from the center of area of the previously mentioned fuzzy triangular non-normalized matrix (as shown in Table 6).

Table 9. Non-normalized pair-wise matrix (obtained from Fuzzy Triangular paired matrix)

Criteria Weight	0.432603	0.173827	0.292055	0.101515
Criteria for Barriers	Barrier B1	Barrier B2	Barrier B3	Barrier B4
Barrier B1	1	2.782043	1.581034	4.223953
Barrier B2	0.396472	1	0.603672	2.000000
Barrier B3	0.681058	1.933402	1	2.929284
Barrier B4	0.246376	0.611111	0.373450	1
Column Sum	2.323906	6.326556	3.558155	10.153237

Similar to the conventional AHP method, the normalizing technique of pair wise matrix is completed by dividing each column value in Table 9 by the sum of the individual columns. The normalized weights of the criteria are calculated by averaging the row-wise values of the normalized pair-wise matrix, as shown in Table 10.

Table 10. Normalized pairwise matrix and criteria weights for verification of experts' judgments

Criteria for Barriers	Barrier B1	Barrier B2	Barrier B3	Barrier B4	Criteria Weights
Barrier B1	0.430310	0.439741	0.444341	0.416020	0.432603
Barrier B2	0.170606	0.158064	0.169659	0.196982	0.173827
Barrier B3	0.293066	0.305601	0.281045	0.288507	0.292055
Barrier B4	0.106018	0.096595	0.104956	0.098491	0.101515
					Sum = 1

The same pairwise comparison matrix from Table 9 (Arithmetic mean of FTNs), which is not normalized, is used to calculate the normalized matrix (Eigen Vector) by multiplying each value in the column by the Criteria weight value (obtained in Table 10). Table 11 displays the obtained Eigen Vectors or criteria weights, their row wise weighted total and the matrix's highest Eigen value *(λ_{max})*. Taking this eigen value, Consistency Index (CI), and Consistency Ratio (CR) are calculated with the help of Eq. (9).

Table 11. Normalized pair wise comparison matrix (Eigen Vector) & CR

Criteria for Barriers	BarrierB1	BarrierB2	BarrierB3	BarrierB4	Criteria Weight	WeightedSum Value	Eigen value = (Weighted Sum ÷ Criteria Weight)
Barrier B1	0.432603	0.483596	0.461748	0.428794	0.432603	1.806741	4.176441
Barrier B2	0.171515	0.173827	0.176305	0.203030	0.173827	0.724677	4.168946
Barrier B3	0.294628	0.336078	0.292055	0.297366	0.292055	1.220127	4.177732
Barrier B4	0.106583	0.106228	0.109068	0.101515	0.101515	0.423393	4.170754
							λ_{max} = 4.173468

The largest Eigen value (λ_{max}) of matrix of order n = 4.173468

Consistency Index (CI) = $(\lambda_{max} - n)/(n-1)$ = 0.057822767

Consistency Ratio (CR) = $\frac{\text{Consistency Index}}{\text{Randam Index (RI)}}$ = 0.064247518

Number of criteria *'n'* equal to 4 and the corresponding Random Index (RI) value is 0.90.

CR < 0.1 that is the weights are acceptable i. e. some small inconsistency is present in judgments.

Using the Eigen vector, the consistency ratio (CR) was determined to be 0.064247518, which is less than 0.1. Therefore, it may be assumed that the matrix is generally consistent and that the research computation has been adequately synthesized for use in the Fuzzy-AHP study of decision-making. All calculations for each step of the Fuzzy-AHP geometric mean methodology, including those for the consistency index (CI) and consistency ratio (CR), are done on a Microsoft Excel sheet.

4. Results and Discussions

The most significant barriers in Bangladesh's RMG industry, and their weights /intensity levels and rankings offer some optimism for decision-makers and business owners looking to enter the fourth industrial revolution. The study's findings indicate that "Lack of Decision makers' support and industry owners' willingness" (Criteria B1) is the most pertinent and important issue (43%), with regard to the implementation of Industry 4.0. Nevertheless, in order to introduce Industry 4.0 technology, the Bangladeshi government frequently sends forth positive signals to businesspeople and affluent citizens. With the assistance of ICT professionals and Industry 4.0-related university researchers, the government of Bangladesh is modifying vocational trades and educational programs for the younger generations with a background in mathematics to meet the demands of the digital world in the future. The government and decision-makers should also pledge their support for financial institutions, steadfast dedication to political stability, and keeping good relations with the nations that serve as Bangladesh's main export markets.

The second-most serious shortcoming, "Lack of Ability to Cover Digital Infrastructure Costs (Criteria B3)," is a substantial barrier to the nation's ability to implement Industry 4.0. This shortcoming is shown to be 29.3%. It should be highlighted that four out of the eleven experts have acknowledged the relevance of both Criteria B1 and B3. As a result, a major roadblock is the investment in small and medium-sized business owners. The government and top management can support enough investment and welcome foreign business people to develop revolutionary technology. The experts in this investigation also recognized "Lack of Technical skills and learning regarding Industry 4.0" (Criteria B2) as a significant barrier (17.5%). People are trying to reskill or improve their skills themselves in response to new technologies and networks because they are worried about their future professions. In order to adapt to new technologies and close the technological gap between education and industry, technical universities are cautiously integrating Fourth Industrial Revolution courses and training. Large firms are setting up technical workshops, training sessions, conferences, and long-term training to fulfil the requirements and shortages of the fourth industrial revolution.

"Availability of a cheaper workforce" (Criteria B4), with a weighted proportion of 10.2% is the fourth-most sensitive and significant barrier to Industry 4.0 adoption in the RMG industry. In RMG factories, traditional physical labor has been slowly replaced by computers and other digital technology. Employees are compensated well overall under this framework, especially technical workforces. The government is deeply concerned regarding pay, safety, health, and other welfare issues affecting industry workers. Although compared to Myanmar, Cambodia, and Vietnam, the workforce in Bangladesh continues to be cheap. To manage the entire transition system, decision-makers and business leaders must practice attentive monitoring.

5. Conclusions

This study determined how these issues affect Ready-Made Garments' transition to Industry 4.0. The study also attempted to determine the interrelationship among environmental barriers and how to eliminate these constraints in order to improve the implementation of new technology. Industry 4.0 barriers in the RMG sector have a detrimental impact on the development of new technology adoption, influencing other linked local impediments. As a result, experts have offered the following recommendations in order to adapt to the present trend of digitization and data interchange in production technologies and take advantage of Industry 4.0 in the RMG sector: 'Lack of decision-makers' support and industry owners' willingness' was identified as the most deficient criteria, followed by 'Lack of Ability to Cover Digital Infrastructure Costs" and further down the list. Locally produced barriers found by review studies will be reduced by policymakers' dedication and industry owners' desire.

The results of the criteria weight values and their ranking generated by applying the provided opinions of experts in the fuzzy-AHP approach are acceptable because the consistency ratio is satisfied. The findings from this study are notably beneficial to businesses and decision-makers that want to analyze various business context difficulties. In addition, the study generated a mathematical model that reveals a practice approach for business executives and academics. Industries should evaluate an additional technical difficulty, the "maturity level of required technologies or Degree of Industry 4.0," to evaluate their technical position after focusing on the main obstacles and the intensity levels for the business environment and prior to implementing Industry 4.0 elements. This is another quantitative research strategy for the key elements of Industry 4.0. RMG employees have extensive experience as well as a wide range of skills and knowledge in various sections, and the industry owners are aware of their worldwide market and business strategy. So, it is high time to study more, research more, get ICT-based skills, and develop training rules to link an integrated approach to developing a positive manufacturing atmosphere by defeating the hurdles for prioritizing the implementation of Industry 4.0.

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