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An MCGDM Approach for Addressing Challenges for Industry 4.0 Adaptation in Heavy Duty Flooring Solution Industries of Bangladesh

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Abstract

The 4th Industrial revolution is the newest advancement in the global industrial sector, which denotes revolutionary shifts in various sectors like manufacturing and service. Customers' individualized needs are a clear indicator of the current state of market instability. Thus, industrial manufacturing systems must be able to adjust to variables like scalability, variety, agility, responsiveness of the system, interconnectivity, data exchange automatically between manufacturing systems, transparency, and human-machine interaction. Since these elements and tenets form the foundation of Industry 4.0 (I4.0), embracing it is indispensable to the long-term sustainability of the global economy. Despite the necessity of implementing I4.0, there is a lack of research on the difficulties that may arise, especially in the heavy duty flooring solution sector in a developing country like Bangladesh. This study attempts to pinpoint the obstacles to I4.0 technology adoption in Bangladesh's heavy duty flooring solution sector. To achieve these goals, Decision Making Trial and Evaluation Laboratory (DEMATEL) has been utilized. Using actual data from a field survey, a numerical illustration has been presented. After the model's validation, checking its robustness, and ranking stability, the best strategy for adopting the I4.0 concept in heavy duty flooring solution industries in Bangladesh is selected.

Keywords
Industry 4.0, Challenges, Heavy duty flooring solution industry, MCGDM, DEMATEL.

1. Introduction
The pace at which technological growth is taking place has provided room for growth and improvement of the fourth industrial revolution, or "industry 4.0" (I4.0), is defined by the incorporation of digital technologies into many facets of industry and production. This technology encompasses several key components among them Cyber-physical system (CPS) is I4.0's foundational technology (Florescu and Barabas 2020). They enables production systems to be flexible and adaptable, enabling the mass manufacture of highly customized goods (Nascimento et al., 2019). The CPS, in fact, bridges the physical and virtual worlds by connecting organizations, corporeal goals, human performers, equipment, and methods across corporate boundaries through IoT communication. They achieve this by transmitting data in real-time for decentralized decision-making processes (Trappey et al. 2017).

Nowadays, business is moving towards the fourth industrial revolution due to customer demands for personalized products, higher quality, shorter delivery times, and automated procedures (Zheng et al. 2021). The previous industrial revolutions such as 1st to 3rd produced significantly higher levels of productivity due to mechanization, electrification, and computer technology (Veza et al. 2015). However, the emerging technology, I4.0, offers numerous assistances, for instance growing productivity, improving excellence, customization and flexibility, supply chain optimization, fostering innovation and competitiveness, and workforce empowerment, etc., across various sectors of the economy. To get these benefits, both developing and developed countries are trying to adopt this emerging technology in their manufacturing and service fields (Zheng et al. 2021).

The consequences of I4.0 on production companies, however, are wide-ranging. It exposes businesses to more intense and occasionally adverse conflict as well as the difficulties of managing significant organizational changes (Travaglioni et al. 2020). Besides, there is scarce research that discusses the opportunities and difficulties related to implementing I4.0 within businesses (Müller et al. 2018). Consequently, there is a noticeable resistance and slow pace in the implementation of I4.0 as a whole within the industrial manufacturing sector as a result of the ambiguity surrounding the perceived potential and difficulties (Kane et al. 2017). It is often known that the adoption process of I4.0 presents technical challenges and cannot be effectively managed if the impact of barriers is overlooked (Kumar et al. 2020; Frank et al. 2019). For most manufacturing companies, especially in developing economies, adopting I4.0 remains something of a dream (Kadir & Broberg, 2020). Adopting this technology in the manufacturing or service field in a developing country like Bangladesh is not as easy as in developed countries like the USA, Canada, and Japan (Luthra & Mangla 2018; Yüksel 2020). This can be attributed to the uneven presentation of government support, culture, infrastructure, skilled labor, economic conditions, and technology support.

So, to reduce the likelihood of failure and stimulate the early adoption of I4.0, it is imperative to comprehend the challenges and how they interact. Given its significance, a growing body of research, like that of (Cugno et al. 2021), aims to pinpoint the obstacles preventing I4.0 from being adopted in different regions and industrial sectors. Even though the aforementioned literature has addressed a variety of I4.0 viewpoints, it appears that the difficulties and solutions for using I4.0 technology in developing nations have not been thoroughly considered. Hence, the authors therefore aim to close this gap. This research aims to explore the obstacles to adopting I4.0 technology in the heavy duty flooring solution industries of Bangladesh by attempting to answer questions (Qs) listed as follows: Q-1: What challenges are heavy-duty flooring solution industries facing for I4.0 adoption? Q-2: How will the challenges be prioritized? To answer these research questions, the following objectives have been defined: Objective 1: To identify the prime challenges for I4.0 adoptions; Objective 2: To investigate the priorities of different challenges. To achieve the above-mentioned objectives, potential challenges for I4.0 adoption is identified by a systematic review of existing literature. Finally, the DEMATEL is used for finding the priorities of the challenges.

2. Literature Review

Bangladesh has taken steps to use I4.0 technology in its manufacturing and services sectors. Its economy is one of the world's fastest-growing where 50.63% of the country's GDP comes from the service sector, 32.80% from industry and 12.46% from agriculture. However, the industrial sector's share is rising (Manik, 2023). The author Manik (2023) also claims that Bangladesh's economy is shifting in favor of industry. The adoption of I4.0 can enhance the intensifying economic growth and speed up output.

The Bangladesh government passed the National I4.0 Policy in 2020 to bring the manufacturing sector of the country modernized. Advanced technologies are being used by the government, the private sector and start-ups to improve productivity, efficiency and competitiveness (Mazumdar and Alharahsheh 2020). The policy illustrates how to digitize and automate industrial processes using IoT, AI and Big Data. I4.0 technologies are part of the Digital Bangladesh initiative, which aims to build a digital ecosystem in the country (Mazumdar and Alharahsheh 2020).

2.1 Barriers to the adoption of Industry 4.0

The I4.0 implementation barriers were explored through the extensive literature review. In order to identify the barriers, the authors conducted a thorough literature review. The Scopus database, Web of Science and Google Scholar were used for this literature search. After reviewing the relevant literature, the authors came up with a list of barriers from Calabrese et al. (2021), Chen et al. (2021), Bhuiyan et al. (2020), Tripathi and Gupta (2021), Hasan et al. (2020), Cimini et al. (2021), Yadav et al. (2020), Moktadir et al. (2018), Stentoft et al. (2020), Shabur et al. (2021), Kumar et al. (2020), Kumar et al. (2022), Yadav et al. (2020), and Weerabahu et al. (2022) which consists of several barriers to I4.0 implementation. Calabrese et al. (2021) claim that to build I4.0 infrastructure, organizations must spend a large amount of money on capital. Moreover, resistance to change is also mentioned as a barrier by the authors. According to Stentoft et al. (2020), to foster the development and the usage of I4.0-compatible hardware, equipment makers must adopt standards that are both thorough and widely accepted. Kumar et al. (2020) and Shabur et al. (2021) stated that motivation for a company is important to make the transition to green manufacturing and waste management. Ciminiet al. (2021) and Hasan et al. (2020) found that an organization's attitude toward exchanging data and materials inside the company is inadequate. Weerabahu et al. (2022) identified digital strategies that consider both the vertical and horizontal parts of the value chain are becoming more and more important to create and use. In the final stage, 14 major barriers to the adoption of I4.0 were selected based on the mentioned articles and professional opinions as shown in Table 1.

Table 1. Technologies of SCM 4.0

Technologies	Notation	References
High-level investment	*O1*	Calabrese et al. (2021), Chen et al. (2021), Bhuiyan et al. (2020)
Inadequate knowledge	*O2*	Tripathi and Gupta (2021), Hasan et al. (2020)
Lack of organizational openness	*O3*	Cimini et al. (2021), Hasan et al. (2020)
Lack of digital communication	*O4*	Yadav et al. (2020a), Moktadir et al. (2018)
Lack of skills and aptitude	*O5*	Calabrese et al. (2021), Stentoft et al. (2020)
Lack of motivation	*O6*	Kumar et al. (2020), Shabur et al. (2021)
Organizational culture	*O7*	Tripathi and Gupta (2021)
I4.0 training	*O8*	Kumar et al. (2020)
Resistance to change	*O9*	Kumar et al. (2022), Joshi et al. (2022), Bhuiyan et al. (2020)
Effective change management	*O10*	Stentoft et al. (2020)
Stakeholders' awareness	*O11*	Kumar et al. (2022), Yadav et al. (2020b), Bhuiyan et al. (2020)
Inadequate standardization efforts	*O12*	Stentoft et al. (2020)
Lack of regulatory framework	*O13*	Calabrese et al. (2021), Bhuiyan et al. (2020)
Lack of digital strategy	*O14*	Weerabahu et al. (2022)

2.2 Literature Survey for MCGDM Models Application

In today's complex and dynamic world, decision-makers often face situations where choices need to be made among alternatives that involve multiple, often conflicting, criteria. In such scenarios, multi-criteria group decision making (MCGDM) model offers a systematic and structured framework to address these challenges and support informed decision-making processes. This modeling can encompass a wide range of domains. To solve decision management problems in a variety of fields, numerous MCGDM models have been proposed by different researchers. From a comprehensive literature review, some key areas and modeling approaches have been demonstrated in Table 2.

Table 2. Application of different MCGDM techniques for supply chain management

Reference	MCGDM models	Field of applications
Nesticò & Somma (2019)	AHP, ELECTRE, TOPSIS, and VIKOR	Enhancement of historical buildings
Ghaleb et al. (2020)	AHP, TOPSIS, and VIKOR	Manufacturing process
Harirchian et al. (2020)	WSM, WPM, AHP, and TOPSIS	RC structures
Kaya (2020)	MABAC and WASPAS	Effect of COVID-19
Madhu et al. (2020)	TOPSIS, VIKOR, EDAS, and PROMETHEE-II	Material selection
Vakilipour et al. (2021)	TOPSIS, SAW, VIKOR, and ELECTRE	Urban life quality
Islam & Arakawa (2022a)	Vague set, HFS, and WGHFPG	Supplier selection
Islam & Arakawa (2022b)	IFS, fuzzy AHP and fuzzy TOPSIS	Supplier selection
Islam & Arakawa (2023)	AHP, TOPSIS, and Rolling Planning	Supplier selection

3. Research Methodology

To attain the objectives of this study, a systematic review of the related literature, expert opinion, and an MCGDM approach is used. Steps involved in this framework are explained as follows:

Step 1: Major barriers for applying I4.0 technologies are identified through a literature review.

Step 2: Key experts, like top and mid-level managers from a renowned company, were interviewed to get their expert opinions on this perspective. A questionnaire was developed for this purpose.

Step 3: A direct relationship matrix is developed by each expert individually to identify the most influential factors as well as estimate their weights.
Step 4: After an individual expert develops a direct relationship matrix, it is aggregated to build up an aggregated direct relationship matrix.
Step 5: The DEMATEL technique is used to estimate the weights of each factor.

4. Methods and Materials

In this study, initially, identified factors are investigated through the DEMATEL method. Because the best approach for analyzing how different components of a complex system are dependent on one another is DEMATEL (Li & Mathiyazhagan, 2017). This method is applied to assign the weights of considered factors.

4.1 Steps in DEMATEL

Step 1: Direct-relation matrix creation: To determine each factor's direct influence, the experts first evaluate the correlation between the sets of paired factors. This assessment is performed using the following rating as follows: 0-No influence, 1- Low influence, 2- Medium influence, 3- High influence, 4-Very high influence, and 5-Extremely high influence. This matrix *A* is formed as shown in Eq. (1).

$$A = \begin{bmatrix} 0 & \dots & a_{1v} \\ \dots & \ddots & \dots \\ a_{v1} & \dots & 0 \end{bmatrix}_{v \times v} \tag{1}$$

Here $i, p = 1, 2, \dots, v$; both parameters define the factors.

Step 2: If there are multiple decision-makers and each decision-maker develop direct-relation matrix individually, then, mean rating is determined to develop a final aggregated direct-relation matrix. For doing this, the Eq. (2) is used to determine the mean rating for the aggregated direct-relation matrix.

$$m_{ip} = \frac{1}{D} \sum_{d=1}^{D} a_{ip}^{d} \tag{2}$$

Here, m_{ip} is the mean rating given by *D* no. of decision-makers. The capital *D* denotes total no. of decision-makers (*d = 1, 2, ..., D)*, and a_{ip}^{d} denotes rating given by the d^{th} decision-maker on factor *i* with respect to factor *p*. After estimating mean ratingm_{ip}, then final *M* matrix is formed as shown in Eq. (3).

$$M = \begin{bmatrix} 0 & \dots & m_{1v} \\ \dots & \ddots & \dots \\ m_{v1} & \dots & 0 \end{bmatrix}_{v \times v} \tag{3}$$

Step 3: Normalization of direct-relation matrix *M*. For doing normalization Eq. (4) is used and normalized matrix is denoted by *Y*.

$$Y = k.M \tag{4}$$

Where,

$$k = \frac{1}{\max\limits_{1 \le i \le v} \sum_{p=1}^{v} a_{ip}} \qquad \text{Here, } i, p = 1, 2, \dots, v \tag{5}$$

Step 4: Construction of total relation matrix *T*. *T* matrix is constructed with the Identity matrix *I* by using Eq. (6).

$$T = Y(I - Y)^{-1} \tag{6}$$

Step 5: The sums of the rows and columns in the *T* matrix are determined by using Eqs. (7) and (8), respectively.

$$R_i = \left[\sum_{p=1}^{v} t_{ip} \right]_{v \times 1} = [t_i]_{v \times 1}, \qquad i = 1, 2, \dots, v \tag{7}$$

$$C_p = \left[\sum_{i=1}^{v} t_{ip} \right]_{1 \times v} = [t_p]_{1 \times v}, \qquad p = 1, 2, \dots, v \tag{8}$$

Step 6: Threshold value (α) estimation: α is estimated by taking the mean value considering all elements from *T* matrix. Here, the capital *N* denotes the number of total elements in the *T* matrix.

$$\alpha = \frac{\sum_{i=1}^{v}\sum_{p=1}^{v}[t_{ip}]}{N} \quad (9)$$

Step 7: Lastly, Eq. (10) is used to evaluate the relative weight of the factor, and Eq. (11) is used to calculate the normalized weight.

$$RW_p = \sqrt{(R_i + C_p)^2 + (R_i - C_p)^2} \quad (10)$$

$$w_p = \frac{RW_p}{\sum_{P=1}^{v} RW_P} \quad (11)$$

5. Results and Discussion

5.1 Estimation of Weights by Using the DEMATEL Method

In this problem, three industry experts were involved to evaluate fourteen challenges which are expressed in the form of *O1, O2, O3, O4, O5, O6, O7, O8, O9, O10, O11, O12, O13* and *O14*. Initially, three experts of a renowned heavy duty flooring solution company were asked to evaluate the fourteen challenges using the following scale: 0-No influence, 1-Low influence, 2-Medium influence, 3-High influence, 4-Very high influence, and 5-Extremely high influence. Using these scale and based on Eq. (1), three experts developed direct relation matrix individually as presented in Table 3-5, respectively. After the construction of initial direct relationship matrix, then these matrices were aggregated to construct a final direct relation matrix. For instance, relational value between *O1* and *O2* was given as a rating of 4 by expert 1 as presented in (1, 2) cell in Table 3. Similarly, relational value between *O1* and *O2* were given 3, and 2 as presented in Table 4, and 5, by expert 2 and 3, respectively. Now, using Eq. (2), aggregated rating was obtained as follows: $\boldsymbol{m_{12}} = \frac{\mathbf{4+3+2}}{\mathbf{3}} = \mathbf{3.00}$.

Similarly, other ratings were also aggregated and finally aggregated direct relation matrix was constructed as shown in Table 6. Now, using Eqs. (4), and (5), aggregated ratings were normalized. For normalization, initially, row-wise all aggregated ratings were summed up then from these summation values, the maximum values were selected based on Eq. (5). For example, using data from Table 6, row-wise summation value of the first row is determined as follows: 3.00 + 3.33 + 2.67 + 2.67+3.67 + 3.67 + 2.67 +3.00 + 2.67 + 3.00 + 3.33 + 3.00 + 3.00 = 39.67. Similarly, other values were also calculated which are shown in last column in Table 6. The maximum value from these calculations was obtained 44.67. Using this value, the normalized rating was determined. For instance, in cell no. (1, 2) i.e. the aggregated rating between *O1* and *O2* was 3.00 and its normalized value is estimated as follows: $\frac{3.00}{44.67} = 0.067 \approx 0.07$. Similarly, other cell values in Table 6 were also normalized, and the final normalized values are presented in Table 7. Then, to find the total relation matrix Eq. (6) is used. For doing this at first identity matrix of same size (14×14) was taken and then subtract by the corresponding value of normalized matrix. Then the obtained matrix was inversed and multiplies by the original normalized matrix. Thus the total relationship matrix was formed as presented in Table 8. Using values from Table 8 and based on Eq. (7), the row sum value was determined.

For example, the sum of the first row is determined as follows: R_1 = 0.69 + 0.80 + 0.84 + 0.77 + 0.79 + 0.92 + 0.90 + 0.88 + 0.79 + 0.83 + 0.86 + 0.89 + 0.94 + 0.93 = 11.83. Similarly, other row sum values were determined as demonstrated in Table 9. Again, using Eq. (8), the column sum value is determined as follows: C_1 = 0.69 + 0.72 + 0.77 + 0.77 + 0.76 + 0.77 + 0.73 + 0.85 + 0.76 + 0.83 + 0.84 + 0.78 + 0.80 + 0.81 = 10.88. Similarly, other column sum values were determined as presented in Table 9. Then, $R_i - C_p$ and $R_i + C_p$ values were determined as presented in Table 9. Then, using Eq. (9), threshold value (α) is determined as follows: $\alpha = \frac{172.45}{196} = 0.88$. Threshold value $\alpha = 0.88$ is compared with the total relation matrix in Table 8. If the cell value of the total relation matrix is higher than α value then it is marked as bold as shown in Table 8. Based on this information the casual diagram is constructed as shown in Figure 1. Then, weights of the challenges are obtained by using Eq. (10) and (11) as shown in Table 9 and in Figure 2.

Table 3. Initial direct relationship matrix developed by expert 1

	O1	*O2*	*O3*	*O4*	*O5*	*O6*	*O7*	*O8*	*O9*	*O10*	*O11*	*O12*	*O13*	*O14*
O1	-	4	3	5	5	2	2	5	4	5	4	3	4	4
O2	1	-	4	3	5	5	2	2	5	4	5	4	3	4
O3	2	1	-	4	3	5	5	2	2	5	4	5	4	3
O4	1	2	3	-	4	3	5	5	2	2	5	4	5	4
O5	2	1	4	3	-	4	3	5	5	2	2	5	4	5
O6	3	2	1	5	4	-	4	3	5	5	2	2	5	4
O7	4	3	2	1	5	4	-	4	3	5	5	2	2	5
O8	3	4	5	2	1	5	4	-	4	3	5	5	2	2
O9	4	3	2	1	5	4	5	4	-	4	3	5	5	2
O10	5	4	3	2	1	5	5	4	3	-	4	3	5	5
O11	4	5	4	3	2	5	5	4	3	4	-	3	5	5
O12	3	4	5	2	1	5	4	3	2	4	5	-	3	5
O13	3	4	5	2	1	5	4	3	2	4	5	3	-	5
O14	3	4	5	2	1	4	3	5	5	2	3	5	4	-

Table 4. Initial direct relationship matrix developed by expert 2

	O1	*O2*	*O3*	*O4*	*O5*	*O6*	*O7*	*O8*	*O9*	*O10*	*O11*	*O12*	*O13*	*O14*
O1	-	3	4	2	2	5	5	2	3	2	3	4	3	3
O2	1	-	3	4	2	2	5	5	2	3	2	3	4	3
O3	5	4	-	3	4	2	2	5	5	2	4	2	3	4
O4	4	5	2	-	3	4	2	2	5	5	2	5	4	2
O5	4	5	2	3	-	3	4	2	2	5	5	2	3	5
O6	2	4	5	2	3	-	3	4	2	2	5	5	2	3
O7	1	2	3	4	2	3	-	3	4	2	2	5	5	2
O8	5	2	2	5	5	4	3	-	3	4	2	2	5	5
O9	2	5	4	2	3	2	2	3	-	3	4	5	2	2
O10	3	2	5	4	2	2	2	4	3	-	3	4	5	5
O11	3	2	2	5	5	5	2	2	4	3	-	3	4	5
O12	4	3	2	4	5	2	2	2	5	4	3	-	5	4
O13	3	4	3	2	5	3	4	5	2	5	4	5	-	3
O14	3	3	4	5	2	4	5	5	2	5	5	4	3	-

Table 5. Initial direct relationship matrix developed by expert 3

	O1	*O2*	*O3*	*O4*	*O5*	*O6*	*O7*	*O8*	*O9*	*O10*	*O11*	*O12*	*O13*	*O14*
O1	-	2	3	1	1	4	4	1	2	1	2	3	2	2
O2	3	-	2	4	1	1	4	4	1	2	1	2	3	2
O3	1	3	-	2	3	4	4	1	1	4	3	1	2	3
O4	2	1	4	-	2	2	4	4	1	1	4	3	1	4
O5	2	1	4	2	-	2	2	4	4	1	1	4	3	1
O6	4	2	1	4	2	-	2	2	4	4	1	1	4	3
O7	3	4	3	1	4	2	-	2	2	1	1	4	4	1
O8	4	3	2	4	4	2	2	-	3	4	2	2	4	4
O9	1	4	3	1	4	4	2	3	-	3	4	1	1	4
O10	2	1	4	1	1	4	4	4	3	-	3	2	4	4
O11	1	2	3	4	4	4	1	2	4	3	-	2	3	4
O12	3	2	1	3	4	1	1	2	1	2	3	-	4	3
O13	2	3	2	1	4	3	4	4	1	1	2	4	-	3
O14	2	2	3	4	1	3	4	4	1	1	2	3	4	-

Table 6. Aggregated direct relationship matrix

	O1	*O2*	*O3*	*O4*	*O5*	*O6*	*O7*	*O8*	*O9*	*O10*	*O11*	*O12*	*O13*	*O14*	*RS*
O1	-	3.00	3.33	2.67	2.67	3.67	3.67	2.67	3.00	2.67	3.00	3.33	3.00	3.00	39.67
O2	1.67	-	3.00	3.67	2.67	2.67	3.67	3.67	2.67	3.00	2.67	3.00	3.33	3.00	38.67
O3	2.67	2.67	-	3.00	3.33	3.67	3.67	2.67	2.67	3.67	3.67	2.67	3.00	3.33	40.67
O4	2.33	2.67	3.00	-	3.00	3.00	3.67	3.67	2.67	2.67	3.67	4.00	3.33	3.33	41.00
O5	2.67	2.33	3.33	2.67	-	3.00	3.00	3.67	3.67	2.67	2.67	3.67	3.33	3.67	40.33
O6	3.00	2.67	2.33	3.67	3.00	-	3.00	3.00	3.67	3.67	2.67	2.67	3.67	3.33	40.33
O7	2.67	3.00	2.67	2.00	3.67	3.00	-	3.00	3.00	2.67	2.67	3.67	3.67	2.67	38.33
O8	4.00	3.00	3.00	3.67	3.33	3.67	3.00	-	3.33	3.67	3.00	3.00	3.67	3.67	44.00
O9	2.33	4.00	3.00	1.33	4.00	3.33	3.00	3.33	-	3.33	3.67	3.67	2.67	2.67	40.33
O10	3.33	2.33	4.00	2.33	1.33	3.67	3.67	4.00	3.00	-	3.33	3.00	4.67	4.67	43.33
O11	2.67	3.00	3.00	4.00	3.67	4.67	2.67	2.67	3.67	3.33	-	2.67	4.00	4.67	44.67
O12	3.33	3.00	2.67	3.00	3.33	2.67	2.33	2.33	2.67	3.33	3.67	-	4.00	4.00	40.33
O13	2.67	3.67	3.33	1.67	3.33	3.67	4.00	4.00	1.67	3.33	3.67	4.00	-	3.67	42.67
O14	2.67	3.00	4.00	3.67	1.33	3.67	4.00	4.67	2.67	2.67	3.33	4.00	3.67	-	43.33
														Max.	44.67

Note: *RS* = Row sum value

Table 7. Normalized matrix

	O1	*O2*	*O3*	*O4*	*O5*	*O6*	*O7*	*O8*	*O9*	*O10*	*O11*	*O12*	*O13*	*O14*
O1	0.00	0.07	0.07	0.06	0.06	0.08	0.08	0.06	0.07	0.06	0.07	0.07	0.07	0.07
O2	0.04	0.00	0.07	0.08	0.06	0.06	0.08	0.08	0.06	0.07	0.06	0.07	0.07	0.07
O3	0.06	0.06	0.00	0.07	0.07	0.08	0.08	0.06	0.06	0.08	0.08	0.06	0.07	0.07
O4	0.05	0.06	0.07	0.00	0.07	0.07	0.08	0.08	0.06	0.06	0.08	0.09	0.07	0.07
O5	0.06	0.05	0.07	0.06	0.00	0.07	0.07	0.08	0.08	0.06	0.06	0.08	0.07	0.08
O6	0.07	0.06	0.05	0.08	0.07	0.00	0.07	0.07	0.08	0.08	0.06	0.06	0.08	0.07
O7	0.06	0.07	0.06	0.04	0.08	0.07	0.00	0.07	0.07	0.06	0.06	0.08	0.08	0.06
O8	0.09	0.07	0.07	0.08	0.07	0.08	0.07	0.00	0.07	0.08	0.07	0.07	0.08	0.08
O9	0.05	0.09	0.07	0.03	0.09	0.07	0.07	0.07	0.00	0.07	0.08	0.08	0.06	0.06
O10	0.07	0.05	0.09	0.05	0.03	0.08	0.08	0.09	0.07	0.00	0.07	0.07	0.10	0.10
O11	0.06	0.07	0.07	0.09	0.08	0.10	0.06	0.06	0.08	0.07	0.00	0.06	0.09	0.10
O12	0.07	0.07	0.06	0.07	0.07	0.06	0.05	0.05	0.06	0.07	0.08	0.00	0.09	0.09
O13	0.06	0.08	0.07	0.04	0.07	0.08	0.09	0.09	0.04	0.07	0.08	0.09	0.00	0.08
O14	0.06	0.07	0.09	0.08	0.03	0.08	0.09	0.10	0.06	0.06	0.07	0.09	0.08	0.00

Table 8. Total relationship matrix

	O1	*O2*	*O3*	*O4*	*O5*	*O6*	*O7*	*O8*	*O9*	*O10*	*O11*	*O12*	*O13*	*O14*
O1	0.69	0.80	0.84	0.77	0.79	**0.92**	**0.90**	0.88	0.79	0.83	0.86	**0.89**	**0.94**	**0.93**
O2	0.72	0.72	0.82	0.78	0.78	0.88	0.88	0.88	0.77	0.82	0.83	0.87	**0.92**	**0.91**
O3	0.77	0.81	0.80	0.80	0.83	**0.94**	**0.92**	**0.90**	0.81	0.87	**0.89**	**0.90**	**0.96**	**0.96**
O4	0.77	0.82	0.86	0.74	0.83	**0.93**	**0.93**	**0.93**	0.81	0.86	**0.90**	**0.93**	**0.97**	**0.97**
O5	0.76	0.80	0.86	0.79	0.75	**0.92**	**0.90**	**0.92**	0.82	0.85	0.86	**0.91**	**0.96**	**0.96**
O6	0.77	0.80	0.84	0.81	0.81	0.86	**0.90**	**0.90**	0.82	0.87	0.86	**0.90**	**0.96**	**0.95**
O7	0.73	0.77	0.81	0.74	0.79	0.88	0.80	0.86	0.77	0.81	0.82	0.87	**0.92**	**0.90**
O8	0.85	0.87	**0.92**	0.87	0.88	**1.01**	**0.97**	**0.91**	0.88	**0.93**	**0.94**	**0.97**	**1.04**	**1.03**
O9	0.76	0.83	0.85	0.76	0.83	**0.93**	**0.90**	**0.91**	0.74	0.86	0.88	**0.91**	**0.94**	**0.94**
O10	0.83	0.85	**0.93**	0.83	0.84	**1.00**	**0.98**	**0.98**	0.86	0.85	**0.94**	**0.96**	**1.05**	**1.04**
O11	0.84	**0.89**	**0.93**	**0.89**	**0.90**	**1.04**	**0.98**	**0.98**	**0.90**	**0.94**	**0.89**	**0.98**	**1.06**	**1.07**
O12	0.78	0.81	0.85	0.79	0.82	**0.92**	**0.89**	**0.89**	0.80	0.86	**0.89**	0.84	**0.97**	**0.97**
O13	0.80	0.86	**0.90**	0.81	0.86	**0.98**	**0.96**	**0.97**	0.82	**0.90**	**0.93**	**0.96**	**0.94**	**1.01**
O14	0.81	0.86	**0.93**	0.86	0.84	**0.99**	**0.98**	**0.99**	0.85	**0.90**	**0.93**	**0.98**	**1.03**	**0.94**

Table 9. Values of row sum, column sum, and estimated weights of the challenges

	R_i	C_p	$R_i + C_p$	$R_i - C_p$	Identity	RW_p	w_p
O1	11.83	10.88	22.72	0.95	Cause	22.74	0.0659
O2	11.59	11.50	23.09	0.09	Cause	23.09	0.0669
O3	12.15	12.13	24.29	0.02	Cause	24.29	0.0704
O4	12.25	11.23	23.49	1.02	Cause	23.51	0.0681
O5	12.06	11.56	23.62	0.50	Cause	23.63	0.0685
O6	12.06	13.18	25.24	-1.12	Effect	25.27	0.0732
O7	11.47	12.88	24.35	-1.40	Effect	24.39	0.0707
O8	13.07	12.91	25.98	0.16	Cause	25.98	0.0753
O9	12.04	11.46	23.50	0.59	Cause	23.51	0.0681
O10	12.94	12.17	25.11	0.76	Cause	25.12	0.0728
O11	13.28	12.42	25.70	0.85	Cause	25.71	0.0745
O12	12.08	12.88	24.97	-0.80	Effect	24.98	0.0724
O13	12.71	13.67	26.38	-0.96	Effect	26.40	0.0765
O14	12.90	13.56	26.46	-0.66	Effect	26.47	0.0767

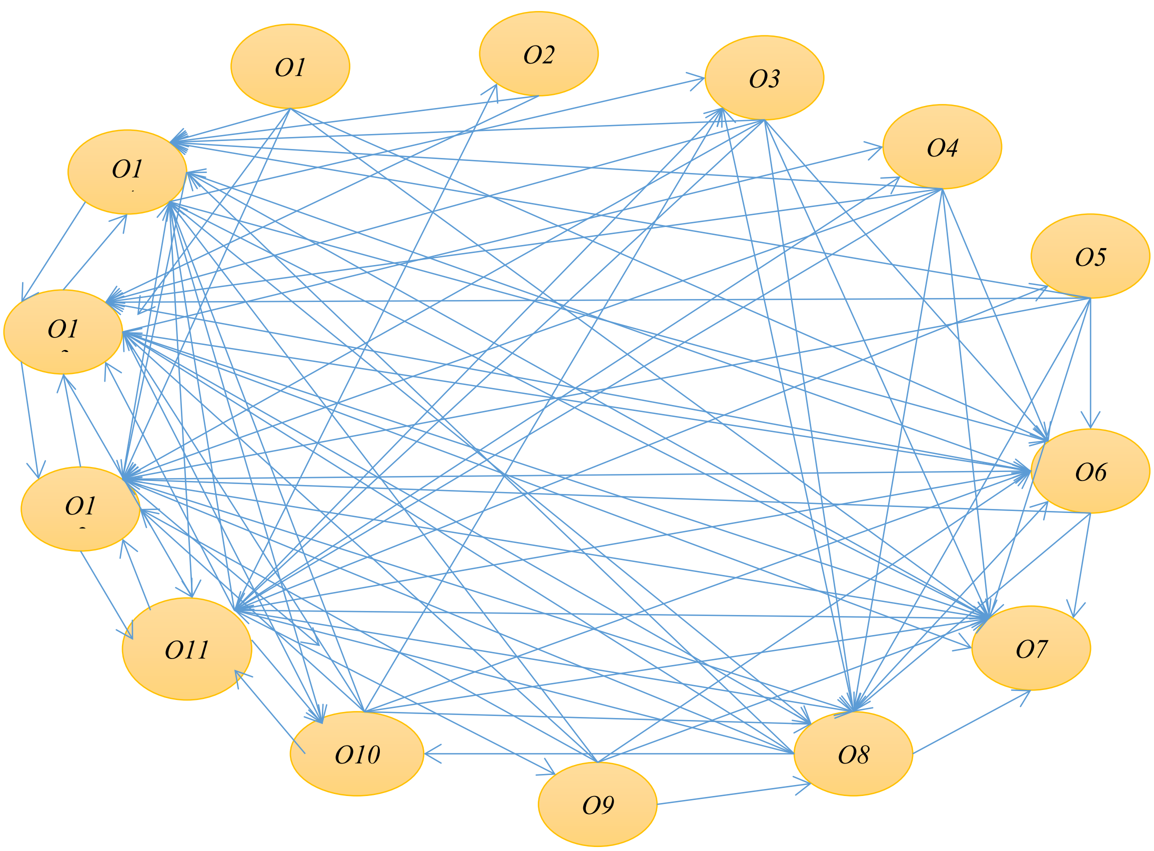

Figure 1. Cause effect diagram

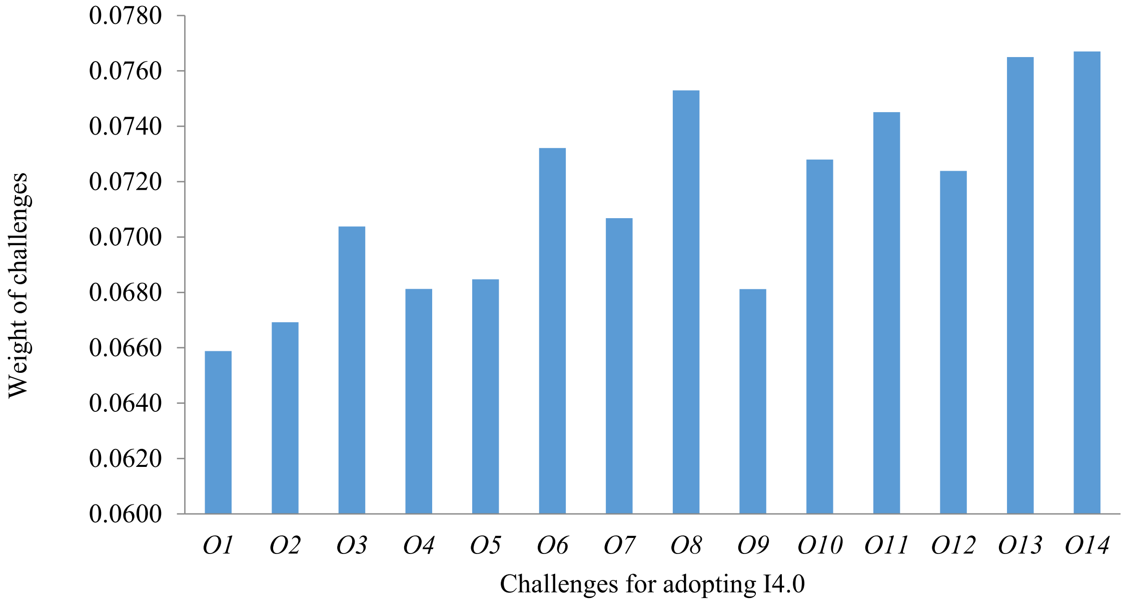

Figure 2. Weight of the challenges.

5.3 Discussion

In this study, the main objective was to identify the prime challenges to implement I4.0 technology in developing country like Bangladesh. To achieve this goal, practical data were collected from three experts who were working in a reputed heavy duty flooring solution company. Initially, identified fourteen challenges were classified into two groups, the cause-and-effect group as shown in Table 9 in the sixth column. The challenge groups O1-O5 and O8-O11 were the cause groups, whereas O6-O7 and O12-O14 were the effect groups. In Bangladesh, for the Heavy Duty Flooring Solution industry identified nine challenges such as “Lack of regulations and standards”, “Government support”, “Security and privacy”, “Environmental impact”, “Inadequate infrastructure”, “Lack of a skilled workforce”, “Competency in new business models”, “Resistance to change”, and “Support from management” which belongs to the cause group is the most responsible challenges for practicing I4.0. For these nine challenges, other five factors such as “contractual and legal uncertainty", “coordination and collaboration difficulties", “lack of awareness", “data management", and “implementation cost” that belonged to the effect group are influenced.

6. Conclusion

The objective of this study was to identify the key challenging factors for I4.0 adaptation in heavy duty flooring solution industries of Bangladesh. Another objective was to assign weights on challenging factors and prioritization of them by using an MCGDM model. In this research, we sought to investigate the critical role of Industry 4.0 practices in Bangladesh. Using a MCGDM method which is DEMATEL, critical challenging factors for I4.0 adaptation in heavy duty flooring solution industries within a developing country were identified and analyzed. The analysis revealed challenging factors and their cause-effect relationship.

Prediction on the future research opportunities would however be to try this issue out in as many industries and locations possible to get more information. In addition, the model applied in this study could be utilized in other areas, like in logistics operations, supplier selection, and operational resilience, among others. Hence through this study, organizations would be able to better cope with adoption challenges and achieve the necessary competitive edge in the current environment characterized by Industry 4.0.

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References

Bhuiyan, A. B., Ali, M. J., Zulkifli, N., & Kumarasamy, M. M. , Industry 4.0: challenges, opportunities, and strategic solutions for Bangladesh. *International Journal of Business and Management Future*, *4*(2), 41–56,2020. https://doi.org/10.46281/ijbmf.v4i2.832

Calabrese, A., Ghiron, N. L., & Tiburzi, L. , 'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework. *Production Planning & Control*, *32*(3), 213–227,2020. https://doi.org/10.1080/09537287.2020.1719715

Chen, S., Liu, X., Yan, J., Hu, G., & Shi, Y. , Processes, benefits, and challenges for adoption of blockchain technologies in food supply chains: a thematic analysis. *Information Systems and e-Business Management*, *19*(3), 909–935,2020. https://doi.org/10.1007/s10257-020-00467-3

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. , How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs. *Journal of Manufacturing Technology Management*, *32*(3), 695–721,2020. https://doi.org/10.1108/jmtm-04-2019-0135

Cugno, M., Castagnoli, R., & Büchi, G. , Openness to Industry 4.0 and performance: The impact of barriers and incentives. *Technological Forecasting and Social Change*, *168*, 120756,2021. https://doi.org/10.1016/j.techfore.2021.120756

Florescu, A., & Barabas, S. A. , Modeling and Simulation of a Flexible Manufacturing System—A Basic Component of Industry 4.0. *Applied Sciences*, *10*(22), 8300,2020. https://doi.org/10.3390/app10228300

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15–26,2019. https://doi.org/10.1016/j.ijpe.2019.01.004

Ghaleb, A. M., Kaid, H., Alsamhan, A., Mian, S. H., & Hidri, L. (2020). Assessment and Comparison of Various MCGDM Approaches in the Selection of Manufacturing Process. *Advances in Materials Science and Engineering*, *2020*, 1–16. https://doi.org/10.1155/2020/4039253

Harirchian, E., Jadhav, K., Mohammad, K., Hosseini, S. E. A., & Lahmer, T. (2020). A Comparative Study of MCGDM Methods Integrated with Rapid Visual Seismic Vulnerability Assessment of Existing RC Structures. *Applied Sciences*, *10*(18), 6411. https://doi.org/10.3390/app10186411

Hasan, M., Rashid, M., Makhdum, N., & Nahid, N. , Fourth Industrial Revolution in Bangladesh: Prospects and Challenges. *Asian Journal of Social Sciences and Legal Studies*, 104–114,2020. https://doi.org/10.34104/ajssls.020.01040114

Islam, M. M., & Arakawa, M. (2022a). Hesitant fuzzy-based integrated multi-criteria group decision-making model for supplier selection. *Journal of Advanced Mechanical Design Systems and Manufacturing*, *16*(4), JAMDSM0034. https://doi.org/10.1299/jamdsm.2022jamdsm0034

Islam, M. M., & Arakawa, M. (2022b). Integrated multi-criteria group decision-making model for supplier selection in an uncertain environment. *Cogent Engineering*, *9*(1). https://doi.org/10.1080/23311916.2022.2079220

Islam, M. M., & Arakawa, M. (2023). Development of an integrated scenario-based stochastic rolling-planning multistage logistics model considering various risks. *Heliyon*, *9*(11), e22289. https://doi.org/10.1016/j.heliyon.2023.e22289

Joshi, S., Sharma, M., Bartwal, S., Joshi, T., & Prasad, M. (2022). Critical challenges of integrating OPEX strategies with I4.0 technologies in manufacturing SMEs: a few pieces of evidence from developing economies. *The TQM Journal*, *36*(1), 108–138. https://doi.org/10.1108/tqm-08-2022-0245

Kadir, B. A., & Broberg, O. (2020). Human well-being and system performance in the transition to industry 4.0. *International Journal of Industrial Ergonomics*, *76*, 102936. https://doi.org/10.1016/j.ergon.2020.102936

Kane, G. C., Palmer, D., Phillips, A. N., Kiron, D., & Buckley, N. (2017, July 13). *Achieving Digital Maturity*. MIT Sloan Management Review. https://sloanreview.mit.edu/projects/achieving-digital-maturity/

Kaya, S. K. (2020). Evaluation of the Effect of COVID-19 on Countries' Sustainable Development Level: A comparative MCGDM framework. *Operational Research in Engineering Sciences Theory and Applications*, *3*(3), 101. https://doi.org/10.31181/oresta20303101k

Kumar, A., Mangla, S. K., & Kumar, P. (2022). Barriers for adoption of Industry 4.0 in sustainable food supply chain: a circular economy perspective. *International Journal of Productivity and Performance Management*, *73*(2), 385–411. https://doi.org/10.1108/ijppm-12-2020-0695

Kumar, R., Singh, R. K., & Dwivedi, Y. K. , Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges. *Journal of Cleaner Production*, *275*, 124063,2020. https://doi.org/10.1016/j.jclepro.2020.124063

Kumar, S., Suhaib, M., & Asjad, M. , Narrowing the barriers to Industry 4.0 practices through PCA-Fuzzy AHP-K means. *Journal of Advances in Management Research*, *18*(2), 200–226,2020. https://doi.org/10.1108/jamr-06-2020-0098

Li, Y., & Mathiyazhagan, K., Application of DEMATEL approach to identify the influential indicators towards sustainable supply chain adoption in the auto components manufacturing sector. *Journal of Cleaner Production*, *172*, 2931–2941,2017. https://doi.org/10.1016/j.jclepro.2017.11.120

Luthra, S., & Mangla, S. K. (2018). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection*, *117*, 168–179. https://doi.org/10.1016/j.psep.2018.04.018

Madhu, P., Dhanalakshmi, C. S., & Mathew, M. , Multi-criteria decision-making in the selection of a suitable biomass material for maximum bio-oil yield during pyrolysis. *Fuel*, *277*, 118109,2020. https://doi.org/10.1016/j.fuel.2020.118109

Moktadir, M. A., Ali, S. M., Kusi-Sarpong, S., & Shaikh, M. a. A. (2018). Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection. *Process Safety and Environmental Protection*, *117*, 730–741. https://doi.org/10.1016/j.psep.2018.04.020

Müller, J. M., Buliga, O., & Voigt, K. , Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, *132*, 2–17,2018. https://doi.org/10.1016/j.techfore.2017.12.019

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L., & Tortorella, G. , Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context. *Journal of Manufacturing Technology Management*, *30*(3), 607–627,2018. https://doi.org/10.1108/jmtm-03-2018-0071

Nesticò, A., & Somma, P. (2019). Comparative Analysis of Multi-Criteria Methods for the Enhancement of Historical Buildings. *Sustainability*, *11*(17), 4526. https://doi.org/10.3390/su11174526

Shabur, A., & Hridoy, M. W. (2021). The investigation of challenges of implementing industry 4.0 in Bangladesh. *Academia Letters*. https://doi.org/10.20935/al775

Stentoft, J., Wickstrøm, K. A., Philipsen, K., & Haug, A. (2020). Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. *Production Planning & Control*, *32*(10), 811–828. https://doi.org/10.1080/09537287.2020.1768318

Trappey, A. J., Trappey, C. V., Govindarajan, U. H., Chuang, A. C., & Sun, J. J. (2016). A review of essential standards and patent landscapes for the Internet of Things: A key enabler for Industry 4.0. *Advanced Engineering Informatics*, *33*, 208–229. https://doi.org/10.1016/j.aei.2016.11.007

Travaglioni, M., Ferazzoli, A., Petrillo, A., Cioffi, R., De Felice, F., & Piscitelli, G. , Digital manufacturing challenges through open innovation perspective. *Procedia Manufacturing*, *42*, 165–172,2020. https://doi.org/10.1016/j.promfg.2020.02.066

Tripathi, S., & Gupta, M. (2021). Identification of challenges and their solution for smart supply chains in Industry 4.0 scenario: a neutrosophic DEMATEL approach. *International Journal of Logistics Systems and Management*, *40*(1), 70. https://doi.org/10.1504/ijlsm.2021.117691

Vakilipour, S., Sadeghi-Niaraki, A., Ghodousi, M., & Choi, S. , Comparison between Multi-Criteria Decision-Making Methods and Evaluating the Quality of Life at Different Spatial Levels. *Sustainability*, *13*(7), 4067,2021. https://doi.org/10.3390/su13074067

Veza, I., Mladineo, M., & Gjeldum, N., Managing Innovative Production Network of Smart Factories. *IFAC-PapersOnLine*, *48*(3), 555–560,2015. https://doi.org/10.1016/j.ifacol.2015.06.139

Weerabahu, W. S. K., Samaranayake, P., Nakandala, D., & Hurriyet, H. , Digital supply chain research trends: a systematic review and a maturity model for adoption. *Benchmarking an International Journal*, *30*(9), 3040–3066,2022. https://doi.org/10.1108/bij-12-2021-0782

Yadav, V. S., Singh, A., Raut, R. D., & Govindarajan, U. H. , Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach. *Resources Conservation and Recycling*, *161*, 104877,2020. https://doi.org/10.1016/j.resconrec.2020.104877

Yüksel, H. , An empirical evaluation of industry 4.0 applications of companies in Turkey: The case of a developing country. *Technology in Society*, *63*, 101364,2020. https://doi.org/10.1016/j.techsoc.2020.101364

Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. , The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *International Journal of Production Research*, *59*(6), 1922–1954,2020. https://doi.org/10.1080/00207543.2020.1824085

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