Drivers and barriers to implementing industrial revolution 4.0 technologies: application of multi-method of ISM-MICMAC-DEMATEL

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Md. Golam Sarower Rayhan, Md. Nurun Nabi and Md. Masum
Department of Textile Engineering Management, Bangladesh University of Textiles, Dhaka, Bangladesh
Saifur Rahman Tushar
Department of Industrial and Production Engineering, Bangladesh University of Textiles, Dhaka, Bangladesh
Monabbir Rafsan Fahim
Department of Textile Engineering Management, Bangladesh University of Textiles, Dhaka, Bangladesh, and
Mohammed Mizanur Rahman
Department of Accounting and Information Systems, Comilla University, Comilla, Bangladesh

Abstract

Purpose – The Textile and Apparel (T&A) industry is a prominent industrial sector continuously evolving with modern production technologies. This study attempts to demonstrate the drivers and barriers to the incorporation of Industrial Revolution 4.0 (IR 4.0) technologies in the T&A industry of manufacturing countries.

Design/methodology/approach – This study has employed the integration of three methods namely Interpretive Structural Modeling (ISM), Matrice d'impacts croisés multiplication appliquée á un classment (MICMAC), and Decision Making and Trial Evaluation Laboratory (DEMATEL).

Findings – From the Interpretive Structural Modeling model, the study found that "Government Schemes" are the most focusing driver to adopt IR 4.0 technologies, and on the contrary, "Organizational Constraints", "Entrepreneurial Technical Inability" and "Non-Availability of Technical Standards & New Technology Accreditation" are the most influential barriers. The MICMAC analysis has plotted the drivers and barriers in four distinct clusters. The DEMATEL analysis illustrates the causal relationship by bisecting the drivers and barriers in the cause-and-effect sections denoting "Entrepreneurial Management Ability (EMA)" to be the most impactful driver and "Organizational Constraints" as the highest considerable barrier.

Practical implications – The outcome of this research work may lead to effective measures undertaken by the industry stakeholders for proper installation and maintenance of IR 4.0 technologies by fostering the relevant drives and mitigating the barriers.

Originality/value – From rigorous literature review it has been assured that previously no research work has been executed for investigating both the drives and barriers altogether for IR 4.0 technologies inclusion in the T&A industry, more precisely following the context of Bangladesh.

Keywords Industrial revolution, Textile and apparel industry, ISM, MICMAC, DEMATEL

Paper type Research paper

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1. Introduction

IR 4.0 is the digital transformation in the field of manufacturing, comprising technologies such as Artificial Intelligence (AI), big data, smart manufacturing, cloud computing, Robotics and many more to create better economic, social and environmental mutuality (Ghobakhloo, 2020). Developed countries have already moved to this transformation process and are leading the progress through enhanced research in this field. Recent works on IR 4.0 context involved the assessment of industrial performance in products and the operational side (Dalenogare *et al.*, 2018), the adoption of technologies to improve environmental sustainability (Javaid *et al.*, 2022), barriers to the adaptation of IR 4.0 in the manufacturing industry (Raj *et al.*, 2020), readiness models (Hizam-Hanafiah *et al.*, 2020) and more on.

The worldwide USD 1.7 trillion apparel market size explains the necessity of IR 4.0 technologies implementation in this T&A industry to keep pace with the rapidly increasing demand for fashion products in the market (Mim *et al.*, 2024). Bangladesh is one of the largest exporters of apparel and has the potential to implement automation in manufacturing by understanding future sustainability via IR 4.0. The findings of (Dal Forno *et al.*, 2023) reported that augmented reality, 3D printing, simulation, etc. can drastically change productivity and cost if applied as automation in manufacturing apparel. Some of the recent works reported new product development processes under IR 4.0 (Wijewardhana *et al.*, 2021), readiness assessment (Lakmali *et al.*, 2020), decision-making in the context of Industry 4.0 (Nouinou *et al.*, 2023), etc. In the context of Bangladesh, supply chain analysis for future alignment with IR 4.0 (Lingkon, 2024), analyzing the key barriers to implementation (Salman *et al.*, 2023), examining the role of Total Quality Management (Saha *et al.*, 2022), etc., are some of the previously published works based on the IR 4.0 concept in the T&A industry.

However, it is observed that the root-level analysis of the IR 4.0 development of the T&A industry is somewhat missing for the fashion manufacturing hubs. There is a clear research gap in finding out what barriers the industry will face in the context of the implementation of IR 4.0 and what motivations will drive industry leaders to take the risk of changing the traditional way of working. The modelling of drivers and barriers, all together with the proposal of multi-attribute decision-making models, necessitates industry leaders, academicians and policymakers to tackle the ongoing and future hurdles with the possible opportunities of IR 4.0 in the industry. The distinct documentation will lead stakeholders to understand and elucidate on critical focus points to drive newer innovation throughout the industry by consolidating the needs of the environment, economy and society. Following this research gap, this research work aims to determine the key drivers and barriers of IR 4.0 in the T&A industry, model with contextual relationships and demonstrate the driving and dependence power of the drivers and barriers based on three of the Multi-Criteria Decision Making (MCDM) methods.

The study attempts to answer the following research questions (RQs):

(1) What are the critical drivers and barriers to IR 4.0 implementation in Bangladesh's T&A industry?

(2) How are the drivers and barriers interrelated in ISM hierarchical models?

(3) How will the drivers and barriers be categorized into MICMAC clusters?

(4) What will be the causal relationships among the drivers and barriers in DEMATEL analysis?

The novel contribution of this research work is that this study will elucidate a scenario of the fundamental components of IR 4.0 technologies for the T&A industry. The interdependence, hierarchy, causal diagrams and connections intensity levels will precisely illustrate the most crucial drivers and barriers, explicitly contributing to the existing literature's need for a systematic analysis. Moreover, the meticulous results of this study will guide industry stakeholders and national policymakers in the formation of favorable policies and legislation of modern technologies' inclusion, considering the corresponding drivers and heading towards influential barriers. To the author's utmost knowledge, the research will be an influential one in engaging both the drivers and barriers in a single study, along with instructing a three-tier MCDM model to construct a wholesome guidance for the global stakeholders related to the textile, fashion and apparel arena.

The latter part of this paper includes an adequate recent literature review in Section 2, research methodology in Section 3, data analysis and results in Section 4, discussion in Section 5, research limitations and future research scope in Section 6 and conclusion in Section 7.

2. Literature review

2.1 Industrial revolution 4.0

The IR can be explained as the emergence of mechanized production processes and the shift towards more machine-oriented industries rather than depending on human labor. The current trending phenomenon, "IR 4.0 or Industry 4.0" is reshaping the world into a future where Intelligent Manufacturing such as cloud computing, Internet of Things (IoT), cyber-physical systems, predictive analysis, software systems in process planning, lean management, sustainability, circularity, Artificial Intelligence (AI), Robotics, Nanotechnology, etc. will take human one step ahead than ever. Industry 4.0 can create a greater emphasis on circular economy implementation (Abdul-Hamid *et al.*, 2024). Industry 4.0 works on a cyber-physical system (CPS), where coordination is achieved between AI, computing networks and human instincts. Digitalization is one of the key elements along with integration among value chains, digitalized products and services and innovative business models are three of the most important principles of IR 4.0 (Abdul-Hamid *et al.*, 2024; De Alwis *et al.*, 2024).

The future of manufacturing industries towards social, economic and environmental sustainability will greatly depend on integrating digital technologies into supply chain management and business strategies, as mentioned by Tao and Chao (2024). Though the work mediated IR 4.0 with sustainable performance, the combination of regulatory limitations, national culture and institutional framework with IR 4.0 needs attention to understand the ground-level condition for a country. Moreover (Joshi *et al.*, 2024), strengthened the concept of Quality 4.0, where data analytics, automation and digital technology have been termed as critical success factors to improve the overall product quality, operational effectiveness, waste reduction, customer satisfaction and sustainable development. However, real-time practical consequences of technologies on workforce adaptability, human resources replaceability, effectiveness of individual sectors and exploration of stakeholders' involvement are necessary to address so that the readiness and impact of Industry 4.0 can be understood, regardless of the country, its structure and legislation.

2.2 IR 4.0 in the textile and apparel industry

According to the study of Sharmin (2022), Bangladesh's RMG industry needs to focus on fields such as R&D, Production, Marketing and IT as they are the crucial ones to benefit from the introduction of IR 4.0. Technologies such as Enterprise Resource Planning (ERP), RFID, sensor technology, cloud technologies, real-time locators and big data analytics are the starting points to implement in the industries (Raj *et al.*, 2020). Automation always comes with a cost, whether the cost of investment, cost of labor cut-off, cost of acceptance, etc. In the case of Bangladesh, technological adaptation, lack of global standards, skilled workforce, policy implementation and availability of the Internet are broader perspectives of challenges. To assess the situation with potential challenges, Hossain *et al.* (2024), proposed the low organizational readiness of Bangladesh's RMG sector to big data analytics and artificial intelligence because of a lack of leadership roles and low engagement of managerial and financial stakeholders. However, a clear indication of government association, relevant policy and legislation, stakeholders' pressure and perspectives and strategic business framework are missing in the current literature that may play a defining role in manifesting the present and future of IR 4.0 to deliver superior sustainable performance, quality and economic growth to the sector (Islam *et al.*, 2024; Pant and Palanisamy, 2025). A complete SWOT analysis on the T&A industries of Bangladesh, Vietnam and China is provided in Figure A1 of Appendix A for better understanding (Hasan Chowdhury *et al.*, 2020; Salman *et al.*, 2024; Yang and Umair, 2024).

2.3 Multi-criteria decision-making (MCDM) related literature

MCDM-based approaches are getting lots of attention to research nowadays. This study employed three integrated MCDM techniques (ISM-MICMAC-DEMATEL) to address mentioned RQs. ISM method enables factor analysis in a constructive hierarchical modeling framework facilitating level wise demonstration in aspect of the factors' momentousness (Tushar *et al.*, 2022). Consequently, MICMAC analysis is an additional feature of TISM method which can provide a clusters view of the factors in four key clusters conditioning on dependency and linkages (Al Zaabi and Bashir, 2020). Furthermore, DEMATEL analysis can illustrate the causal relationship among the factors with degree of effect diagram of each factor on other factors (Al Zaabi and Bashir, 2020). The proposed MCDM models complement each other's findings and deliver a superior outcome for manufacturing industries, thus becoming a trusted source for the authors. Table 1 shows the other literature works on ISM, DEMATEL & MICMAC.

3. Methodology

3.1 Data collection

This study approaches for data collection in three steps. At first, an intensive literature review is required to find out IR 4.0 drivers and barriers. For the literature review, journal articles from Scopus and Web of Science indexed databases will be collected and reviewed for the most important drivers and barriers towards IR 4.0 technologies in T&A industry. Drivers and barriers related to IR 4.0 in the case of other industries will also be prioritized. MCDM techniques require small focus group survey in every data collection steps. The sample size is smaller in the case of MCDM studies because the quantity is somewhat less important here in comparison to the expertism level of the experts. Moreover, models like DEMATEL, ISM, etc. contain complex matrices, pairwise comparisons and require proper explanation to get the most accurate information from experts. The smaller sample size reduced large sample biases, enhanced validation accuracy and eradicated the hassle for the researcher (Manoharan *et al.*, 2022). The literature identified drivers and barriers will be sent to industry and academic experts to check the relevance with the T&A industry, especially in the case of Bangladesh. In the second stage, the most relevant drivers and barriers will undergo feedback rating for well-known Pareto criteria (80/20 rule) analysis. Then, in the third stage, contextual relationships among the most crucial drivers and barriers will be developed by a small group of industry and academic experts. This research work has followed the following research framework as illustrated in Figure 1.

3.2 Interpretive structural modeling (ISM)

ISM method implies a qualitative technique by which a complex matrix structure developed from expert judgment can be converted to a conveniently realizable structural model (Warfield, 1974). This method is generally suitable for managerial implications where influential interrelationships among the variables have to be demonstrated. The consequential steps of the ISM method are as follows (Cheng *et al.*, 2023; Wang *et al.*, 2023):

Step 1: The variables are identified through an intensive literature review.

Step 2: A contextual relationship among the variables is developed.

Table 1. Recent literature on the MCDM approach

Author	Objective	Limitation	Industry/Sector	Methods
Salman *et al.* (2023)	To illustrate the barriers to adoption of IR 4.0 in Bangladesh	Less applicable to other industries, ignored cultural and social perspectives, and study bias may occur	Ready-made garments Industry	DEMATEL
Drumond *et al.* (2021)	To examine the interaction between the marketing criteria	Lack of real-time marketing action-relationship identification	Manufacturing Industry	
Nimawat and Gidwani (2021)	To explore the relevant barriers to IR 4.0 adoption and demonstrate causal relationships among them	Chances of some missing barriers, and the possibility of prejudiced expert judgement		
Nida *et al.* (2024)	To create a structural relationship between the enablers of sustainability adoption	Lack of diversified data collection and comparability to other models		ISM & MICMAC
Chanchaichujit *et al.* (2024)	To investigate the barriers to the adoption of IR 4.0 technologies	Lack of strategic framework and timeline discussions to guide stakeholders	Agricultural sector	
Roy Ghatak and Garza-Reyes (2024)	To examine the barriers to Industry 4.0 adoption in the quality management concept	Lack in segmentation and analysis on specific manufacturing sectors	Manufacturing Industry	
Swain *et al.* (2024)	To demonstrate the contextual relationship among the obstacles of serving mobile health	Lack of quantifying the impact of each aspect	Health care industry	ISM & MICMAC
Liu *et al.* (2024)	To examine the critical factors towards organizational resilience	Ignorance of geographic and construction difficulties in selecting critical factors	Transportation industry	ISM, MICMAC & DEMATEL

Source(s): Authors' own work

Step 3: The development of the Structural Self-Interaction Matrix (SSIM)

SSIM has been developed by placing symbolic values like V, A, X and O from the expert judgment as the influential relation between the factor "m" and "n" (Karmaker *et al.*, 2023):

(1) V: Variable m affects variable *n*.

(2) A: Variable m is affected by variable *n*.

(3) X: Variables m and *n* affect each other.

(4) O: Variables m and *n* are unrelated.

Step 4: Development of the initial reachability matrix from the SSIM. Symbolic terms are converted to corresponding binary numbers as V (1,0), A (0,1), X (1,1) and O (0,0).

Step 5: Construction of the final reachability matrix from the initial reachability matrix by checking transitive (indirect) links among the variables. The transitivity checking criteria

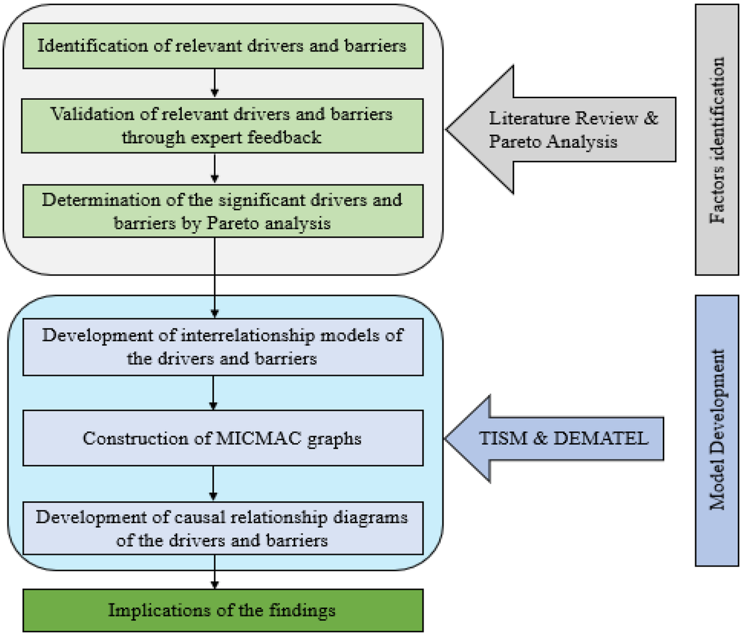

Figure 1. Proposed research framework. Source: Authors' own work

implies that if "Variable-1" influences "Variable-2", "Variable-2" influences "Variable-3," then the resultant is "Variable-1" influences "Variable-3".

Step 6: The variables are then categorized into several levels utilizing the reachability set, antecedent set and corresponding intersection set. The reachability set denotes the portion of variables that are influenced by other variables and itself. The antecedent set implies part of variables that affect others and itself.

Step 7: A digraph is then developed according to the variables placed in the intersection set as per level partitioning. ISM model is also constructed from the diagraph.

3.3 MICMAC

MICMAC analysis provides a cluster view of the variables by utilizing the driving and dependence power of the variables (Bari *et al.*, 2022). The variables are plotted in the following four clusters (Rahman *et al.*, 2022).

(1) Autonomous cluster of variables with low driving power and low dependence power.

(2) Dependent cluster of variables with low driving power and high dependence power

(3) Linkage cluster of variables with high driving power and high dependence power

(4) Independent cluster of variables with high driving power and low dependence power.

3.4 DEMATEL

The DEMATEL method was first introduced by the Battele Memorial Institute of Geneva between 1972 and 1976 (Wu and Chang, 2015). It closely demonstrates a set of variables by determining causal relationships among them through expert judgment with the help of a digraph (Peng and Tzeng, 2019; Shieh and Wu, 2016). This method consists of the following steps-

Step 1: Formation of the pairwise matrix of the variables with expert's rating points based on the linguistic scale. Linguistic symbols are No Influence, Low Influence, Medium Influence and Strong Influence denoted by corresponding rating points 0, 1, 2 and 3 respectively.

Step 2: Obtaining the average score of the rating points

$$a_{ij} = \frac{1}{H} \sum_{K=1}^{H} X_{ij}^{K}$$

Step 3: Formation of a normalized direct relationship matrix D

$$D = [A] \times K;\ \text{Where}, K = \text{Min}\left[\frac{1}{\max \sum_{j=1}^{n} a_{ij}}, \frac{1}{\max \sum_{i=1}^{n} a_{ij}}\right]$$

Step 4: Obtaining the total relationship matrix T, $T = D\,(I - D)^{-1}$

Step 5: Summation of the rows (R) and summation of the columns (C)

$$R_i = \sum\nolimits_{i=1}^{n} t_{ij}\,;\ C_j = \sum\nolimits_{j=1}^{n} t_{ij}$$

Step 6: Calculation of (R + C) and (R − C).

Step 7: Formation of the digraph using values of (R + C) and (R − C).

Step 8: Determination of which are causal, and which are affected among the variables.

4. Analysis and results

4.1 Pilot survey

After rigorous literature scrutiny, this study has identified 13 key drivers and 13 key barriers for IR 4.0 technologies. Primary identified drivers and barriers with brief descriptions have been listed in Tables A1 and A2 of Appendix A, respectively. Then all the drivers and barriers were sent to 30 experts from both industry and academia to check their relevance in the T&A industry. However, 23 experts provided complete judgment regarding the relevancy of the drivers and barriers.

4.2 Identification of most significant drivers and barriers using Pareto analysis

The second stage of data collection comprises Pareto analysis which enables to identification of the most crucial variables from the primary variables set. Pareto analysis is performed based on the 80/20 rule, which implies that 20% of the causes account for 80% of the effects (Rahman *et al.*, 2022). Pareto analysis discovers the most significant variables by focusing on the cumulative percentage values of the rating points from industry and academic experts' judgment. Experts were provided a rating criterion comprising 1–9, where 1 implies less priority and 9 denotes topmost priority. Primary identified relevant drivers and barriers were sent to 23 experts who had responded in the pilot survey stage. However, 17 complete responses have been achieved from Pareto analysis. The demographics of the respondents have also been provided in Table A3 of Appendix A. Pareto charts of drivers and barriers are provided in Figures A2 and A3 in Appendix A.

4.3 Finalized drivers and barriers of IR 4.0 implementation

After a successful relevancy check and significance analysis, the study found 8 key drivers out of 13 drivers and 9 major barriers out of 13 primary selected barriers. The major drivers and barriers have been provided in Table 2.

4.4 Model development of drivers and barriers by ISM

The most significant eight drivers and nine barriers were then presented to 17 high-level experts from industry and academic backgrounds for their judgments, based on a linguistic scale in matrix form, to develop SSIM. However, 10 experts provided their complete feedback on this matrix development. The experts were properly explained about the drivers and barriers and put their impactful insights in Yes/No options. Their responses have been converted to symbolic forms as V, A, X and O for the influential drivers and barriers (Aggarwal *et al.*, 2023). The developed matrices for the IR 4.0 drivers and barriers have been illustrated in Table A4 of Appendix A. Initial reachability matrices for drivers and barriers have been provided in Table A5 of Appendix A. The driving and dependence power values have been determined by summing up the corresponding binary values. After ascertaining all the transitive links, the final reachability matrices (Table A6 of Appendix A) have been developed along with new

Table 2. Finalized drivers and barriers of IR 4.0

Drivers	D2	Government schemes	Sureeyatanapas *et al.* (2023), Abdul-Hamid *et al.* (2024), Shant Priya *et al.* (2023)
	D4	Coherent strategic plan	Romanello and Veglio (2022), Abdul-Hamid *et al.* (2024), Mim *et al.* (2024)
	D6	Entrepreneurial management ability (EMA)	Kumar *et al.* (2022), Abdul-Hamid *et al.* (2024)
	D7	Stakeholder collaboration	Kumar *et al.* (2022), Rajput and Singh (2019), Shant Priya *et al.* (2023)
	D9	Smart supply chain management	De Alwis *et al.* (2024), Abdul-Hamid *et al.* (2024), Nick *et al.* (2020)
	D10	Smart quality monitoring	De Alwis *et al.* (2024), Rajput and Singh (2019)
	D11	New digital technologies	Romanello and Veglio (2022), Abdul-Hamid *et al.* (2024), Nick *et al.* (2020), Mim *et al.* (2024)
	D13	Organizational awareness and monitoring	Sureeyatanapas *et al.* (2023), Nick *et al.* (2020), Tortora *et al.* (2021)
Barriers	B2	Employee resistance to change	Sureeyatanapas *et al.* (2023), De Alwis *et al.* (2024), Goswami and Daultani (2022)
	B3	Organizational constraints	Sarkar *et al.* (2023), Fekrisari and Kantola (2024), Sureeyatanapas *et al.* (2023)
	B5	Entrepreneurial technical inability	De Alwis *et al.* (2024), Gouda and Tiwari (2024)
	B6	Insufficient digital and physical infrastructure	Fekrisari and Kantola (2024), Sureeyatanapas *et al.* (2023), Roy Ghatak and Garza-Reyes (2024)
	B7	Lack of skilled workforce	Sureeyatanapas *et al.* (2023), De Alwis *et al.* (2024), Chanchaichujit *et al.* (2024), Salman *et al.* (2023)
	B8	Inadequate training for digital competencies	Sarkar *et al.* (2023), Sureeyatanapas *et al.* (2023), Shang *et al.* (2022)
	B9	Non-availability of technical standards and new technology accreditation	Sarkar *et al.* (2023), Sureeyatanapas *et al.* (2023), De Alwis *et al.* (2024), Chanchaichujit *et al.* (2024)
	B11	Ambiguity about digital investments	Sarkar *et al.* (2023), Sureeyatanapas *et al.* (2023), De Alwis *et al.* (2024)
	B13	High initial investment cost	Aggarwal *et al.* (2023), Fekrisari and Kantola (2024), Sureeyatanapas *et al.* (2023)

Source(s): Authors' own work

driving and dependent power for the drivers and barriers respectively. Transitive relationships are shown by the 1* symbol in the final reachability matrices. From the final reachability matrix, the reachability set and antecedent set for the variables have been derived. After ascertaining both sets (reachability and antecedent) for the drivers and barriers, the intersection set has been determined. The drivers and barriers have been segregated in different levels as provided in Table A7 of Appendix A. Similar drivers and barriers are ordered at the same level. The drivers and barriers are then arranged in a vertical structural model as per level partitioning combining all the direct and transitive links. Figures 2 and 3 illustrate interpretive structural models for the drivers and barriers respectively.

4.5 MICMAC analysis

MICMAC analysis elucidates cluster view of the drivers and barriers by dividing them in different clusters in graphical format with their driving and dependance power. Figure 4 illustrates MICMAC graphs for the drivers and barriers respectively.

4.6 Causal relationship analysis of the drivers and barriers

Ten experts who participated in ISM modeling were invited to provide feedback ratings to build the direct relationship matrix by commencing the average rating matrices for drivers and

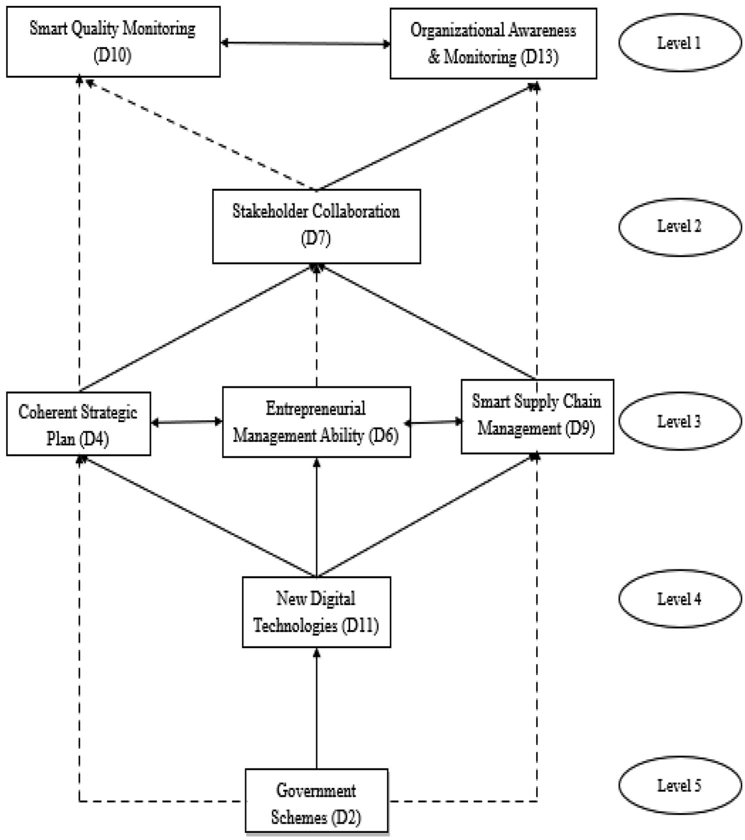

Figure 2. Interpretive structural model of the drivers. Source: Authors' own work

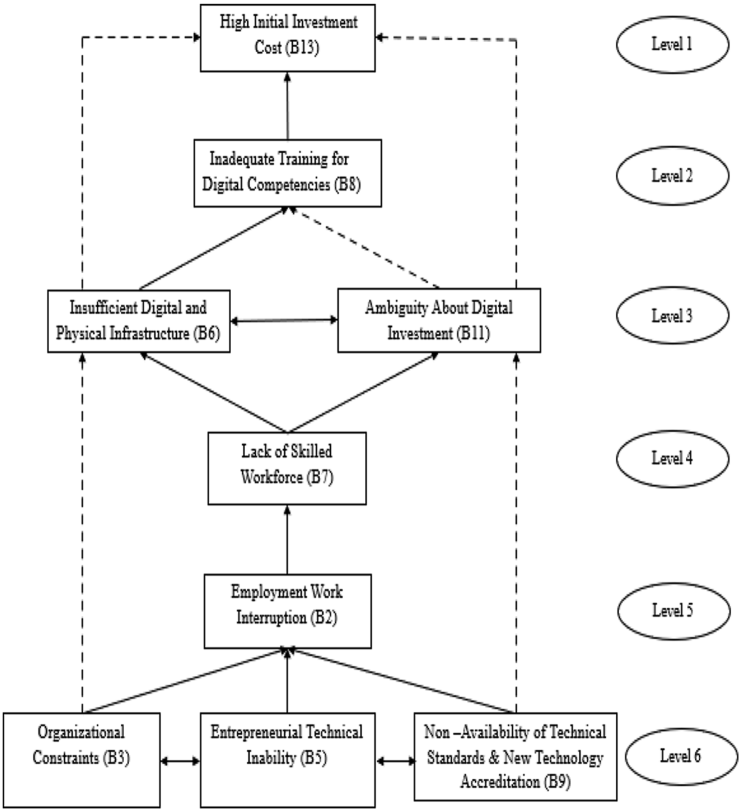

Figure 3. Interpretive structural model of the barriers. Source: Authors' own work

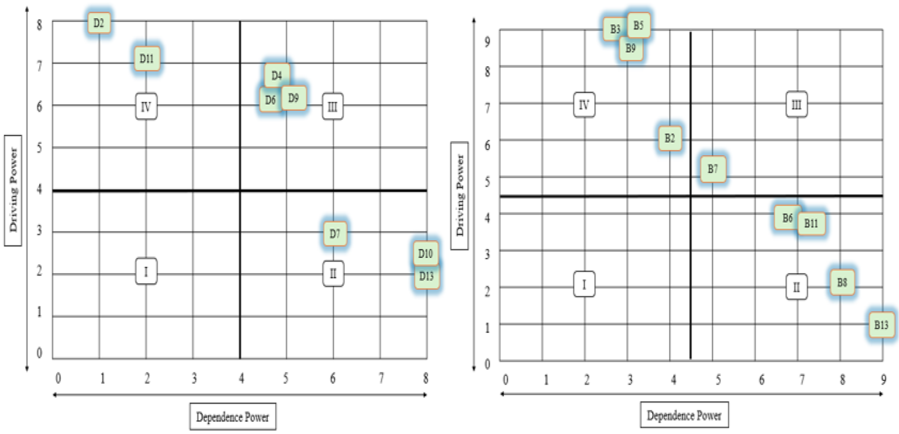

Figure 4. (a) MICMAC of the drivers (left) and (b) MICMAC of the barriers (right). Source: Authors' own work

barriers as presented in Table B1 of Appendix B. Direct relationship matrices (D) and total relationship matrix (*T*) were determined following Steps 2, 3 and 4 of Section 3.3. The matrices are presented in Tables B2 and B3 of Appendix B. The summation of row values from the *T* indicates *R*, while the summation of column values denotes C. The (R + C) values indicate the severity of the variables. In the case of (R − C), a positive value implies "cause," while a negative value denotes "effect" for the variables. Table 3 illustrates the (R + C) and (R − C) values for drivers and barriers for severity ranking, and Figure 5 denotes the cause–effect groups, respectively. The degree of effect matrices for the drivers and barriers is provided in Table B4 of Appendix B, and the degree of connections among the variables is provided in Figures B1 and B2 of Appendix B.

4.7 Sensitivity analysis

To justify the reliability of the results obtained from DEMATEL analysis, sensitivity analysis is required by definite investigation runs (Karuppiah *et al.*, 2025). It has been executed through 4 investigation trial runs by providing varying weights to 4 experts, keeping other weights constant. In the case of run 1, Expert 1 held highest weighted value (0.4) considering equal weighted value (0.2) for others (Garg, 2021) as provided in Table B5 of Appendix B. Investigation run 1 for IR4.0 drivers revealed most vital drivers as D6 > D4 > D11 > D13 > D10 > D9 > D7 > D2. Among the drivers, D2, D7 and D11 indicate cause group and D9, D10, D4, D13 and D6 belong to effect group. Results from investigation run 1 completely support the outcomes obtained from DEMATEL analysis. Consequently, investigation run 2, 3 and 4 from rest 3 experts also provided the similar results like run 1. Consequently, investigation run 1 for IR4.0 barriers signified most impactful barriers series as B3 > B9 > B8 > B6 > B2 > B5 > B7 > B11 > B13. Among the barriers, B3, B11 and B13 indicate cause group and B9, B6, B2, B8, B7 and B5 belong to effect group. This series and cause-effect categorization also similar to the results achieved from DEMATEL analysis. Investigation run 2, 3 and 4 also provided the same results with closer values. The cause–effect outcomes from sensitivity analysis results have been provided in Tables B6, B7, Figures B2 and B3 of Appendix B.

Table 3. Influential and causal relationship of the drivers and barriers

		R + C	Rank	R − C	Cause/effect
Drivers	D2	5.431	8	2.175	Cause
	D4	9.126	2	−0.525	Effect
	D6	9.447	1	−1.371	Effect
	D7	7.926	7	0.120	Cause
	D9	8.037	6	−0.008	Effect
	D10	8.155	5	−0.230	Effect
	D11	8.761	3	1.145	Cause
	D13	8.453	4	−1.305	Effect
Barriers	B2	9.058	5	−0.224	Effect
	B3	10.825	1	0.057	Cause
	B5	8.966	6	−1.445	Effect
	B6	9.111	4	−0.137	Effect
	B7	8.598	7	−1.082	Effect
	B8	9.180	3	−0.293	Effect
	B9	9.926	2	−0.076	Effect
	B11	8.434	8	1.576	Cause
	B13	7.171	9	1.931	Cause

Source(s): Authors' own work

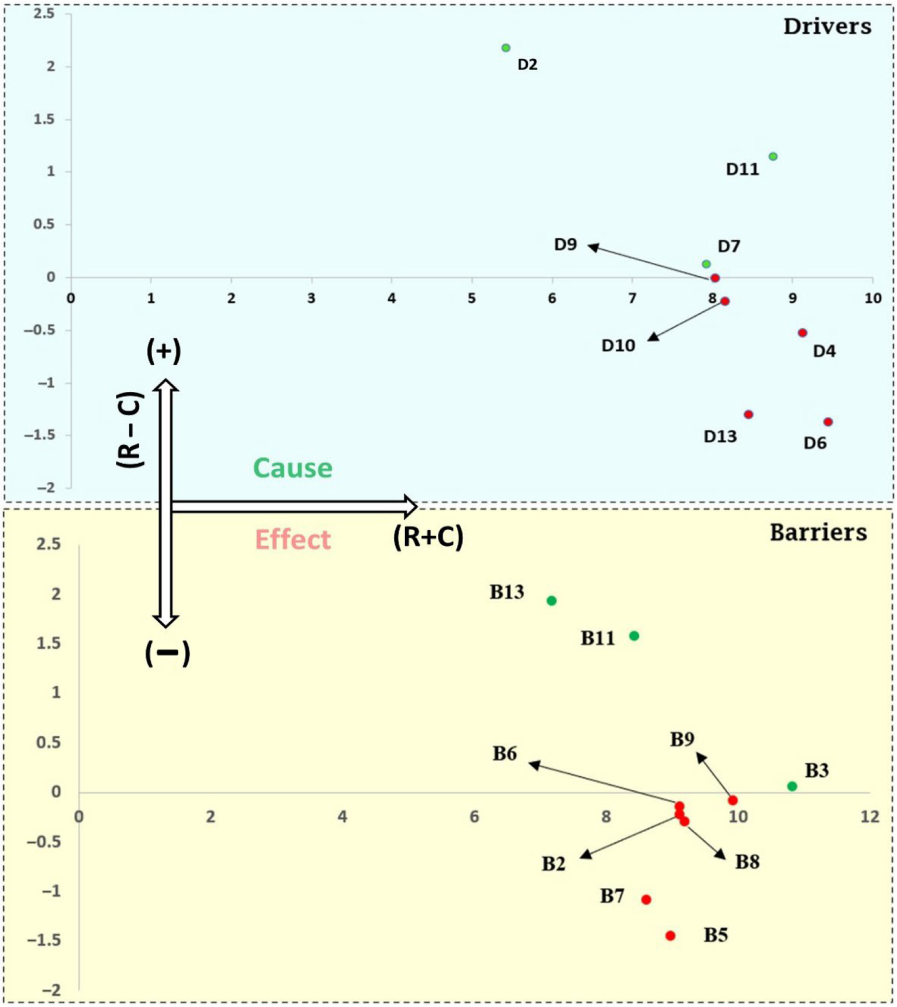

Figure 5. Degree of effect diagram of the (a) drivers (top) and (b) barriers (bottom). Source: Authors' own work

5. Discussions

The hierarchical model of the drivers has been illustrated in Figure 2. The level-wise partition of the drivers shows that "Government Schemes (D2)" is the most impactful driver, showing the highest driving power with the lowest dependence in level 5. As IR 4.0 technologies adoption is still a matter of ambiguity for the industry stakeholders, promotional government schemes like financial incentives, favorable export-import policies and tax rebate policies can boost digital technologies integration in the present manufacturing system (Abdul-Hamid *et al.*, 2024; Sureeyatanapas *et al.*, 2023). After level 5, the most influential driver is "New Digital Technologies (D11)", placed in level 4. Adopting new digital technologies can speed up manual and semi-automatic operations (Nick *et al.*, 2020; Romanello and Veglio, 2022). The drivers are also placed in the independent cluster of MICMAC analysis that supports the findings. Finally, in level 1, two rest drivers exist as "Smart Quality Monitoring (D10)" and

"Organizational Awareness and Monitoring (D13)". As smart technologies can modify the production process, smart and advanced quality monitoring is inevitable (De Alwis *et al.*, 2024; Rajput and Singh, 2019). The last three drivers have been plotted in the dependent cluster of MICMAC analysis. In the case of transitivity checking, the study found an influential transitive link (indirect effect) between "Entrepreneurial Management Ability (D6)" and "Stakeholder Collaboration (D7)". Alongside, another transitive link between "Stakeholder Collaboration (D7)" and "Smart Quality Monitoring (D10)".

The hierarchical model of the barriers in Figure 3 reveals that "Organizational Constraints (B3)", "Entrepreneurial Technical Inability (B5)" and "Non-Availability of Technical Standards & New Technology Accreditation (B9)" possessed the highest driving power with the lowest dependence power (Sarkar *et al.*, 2023). have indicated the relevance of these three barriers to IR 4.0 implementation. At level 5, only one barrier gets connected as "Employee Resistance to Change (B2)". This barrier has a direct influence on the three barriers in level 6. When an organization takes the initiative to handle entrepreneurial technical issues for installing new technological features in running system, current employees' normal working process can be interrupted and in most cases, employees are reluctant to a new change (Chanchaichujit *et al.*, 2024; Goswami and Daultani, 2022; Salman *et al.*, 2023). Finally, barrier "High Initial Investment Cost (B13)" is placed in level 1, implying the highest dependent power and lowest driving power. Since IR 4.0 will modify the current manufacturing system, and the initial financial investment will be so high, it is important to mitigate lower-level barriers for long-term profit indication (Aggarwal *et al.*, 2023; De Alwis *et al.*, 2024).

Through the DEMATEL analysis from Table 3 and Figure 5, it has been clarified that the drivers "Government Schemes (D2)", "Stakeholder Collaboration (D7)" and "New Digital Technologies (D11)" refer to the cause group. On the contrary, the drivers "Coherent Strategic Plan (D4)", "Entrepreneurial Management Ability (EMA) (D6)", "Smart Supply Chain Management (D9)", "Smart Quality Monitoring (D10)" and "Organizational Awareness and Monitoring (D13)" fall under effect group. The study found the prioritization of the drivers by commencing $(R + C)$ values in the sequence of D6 > D4 > D11 > D13 > D10 > D9 > D7 > D2. Moreover, analysis for the barriers revealed, "Ambiguity about Digital Investments (B11)", "High Initial Investment Cost (B13)" and "Organizational Constraints (B3)" as the prominent cause factors. On the other hand, the rest six barriers are the most affected ones. The values of $(R + C)$ reveal the severity series similarly as B3 > B9 > B8 > B6 > B2 > B5 > B7 > B11 > B13.

5.1 Significance of the study

Policymakers can identify the Government scheme (D2), New Digital Technologies (D11) and Stakeholders' collaboration (D7) as the critical drivers to implement in the shortest possible time. Textile manufacturing countries may operate under different conditions; however, the government's interest in proposing varied schemes, tax incentives, differentiated VAT fees and collaboration with technology-sharing organizations will encourage managers to persuade their stakeholders to support innovation in their value chain (Majumdar *et al.*, 2021). Stakeholder engagement plays a crucial role in shaping industry flow by influencing key players in both backward and forward linkages. Stakeholders' perspectives and government initiatives will drive the adoption of future technologies in material procurement, processing, testing and recycling (Salman *et al.*, 2024).

Similarly, IR 4.0 implementation needs to overcome barriers of the Organizational Constraints (B3), Entrepreneurial Technical Ability (B5), Non-Availability of Technical Standards & New Technology Accreditation (B9) and Ambiguity about Digital Investment (B11) at the shortest possible time. Organizational mindset, vision and goals are important in shaping the behavior of its managerial level, as well as these factors visualize the innovative consideration of the top-level management (Zhang *et al.*, 2024). The T&A sector vastly depends on the linear production and material handling processes, even if the environmental degradation is maximized throughout the years (Van Ta *et al.*, 2024). However, regulatory bodies need to strengthen the standards and accreditation to set the guidance for the industry so that SMEs can find a solid ground to implement regulations towards the betterment of people, planet and profit (Safavi Jahromi and Ghazinoory, 2025).

5.2 Theoretical contributions

This research work is one of the preliminary empirical studies examining the influential drivers and barriers altogether for IR 4.0 technological integration in the context of the textile and apparel industry. It develops a thorough evaluation of the critical drivers and barriers by incorporating industry experts and literature support that increases the accountability of the study against existing literature.

Moreover, the application of MCDMs builds a three-tier structure of hierarchical significance, dependence-independence linkages and degree of effect contributes as a foundation of the existing and future research works.

Finally, this paper highlights current drivers and barriers to the use of IR 4.0 in Bangladesh as well as the global context. This is the novel contribution since the combined perspective has not yet been properly explored, and research has not been conducted on IR 4.0 drivers and barriers altogether.

5.3 Managerial implications

Firstly, the research consolidates the critically essential drivers and barriers into one demonstration that will help stakeholders analyze and determine future strategies for the T&A industry worldwide.

Secondly, the modular framework and causal diagram of the drivers and barriers elucidate the impactful interrelations that can assist industry stakeholders in defining short, intermediate and long-term goals.

Moreover, this study enables managers to assess the influence of IR 4.0 on their company operations, potentially leading to enhanced efficiency, productivity and competitiveness.

Finally, the outcomes can also contribute to national policymaking for the overall government schemes toward IR 4.0 technologies that enrich the T&A industry.

5.4 Social and environmental implications

(1) The study explicitly outlines the use of IR 4.0 technologies to enhance workplace safety and health, mitigate human errors, improve communication and alleviate the burden, therefore fostering a more adaptable working environment.

(2) The research illustrates the use of IR 4.0 technologies in customer-valued product design to meet the needs of consumers via a user-friendly environment and urges recognition of the true worth of Industry 4.0 to sustainable manufacturing.

(3) The alignment of technologies will ensure efficient production, reduction of energy losses, less generation of greenhouse gases by tracing and tracking and environmental monitoring via automation that leads to a more robust and circular textile industry.

6. Conclusion

Investigating the potential of IR 4.0 in the Textile and Apparel sector, one of the promising and growing billion-dollar industries, the present work attempts to formulate a contextual model as a guideline framework and causal diagrams for the drivers and barriers of IR 4.0 technologies' inclusion. The outcomes of the three-tier ISM–MICMAC–DEMATEL models facilitated government schemes, new digital technologies and stakeholders' collaboration as the most crucial drivers that the stakeholders should address shortly. The collaboration of the industry experts and academicians pointed out organizational constraints, entrepreneurial technical ability, lack of technical standards and accreditation and ambiguity about digital investment may come up with a headache for policymakers, managers and regulators. The valuable insights and findings from the study can illustrate the visionary and multi-dimensional view of digital technology management by accelerating the driving factors and mitigating the challenging factors.

6.1 Research limitations and future scope

Firstly, this research attempts to oversee the entire T&A industry from a bird's eye view, not any specific backward linkage sectors of the industry. Secondly, this work acknowledges the existing constraints, suggesting that future research might enhance the model by including other hurdles. The model is constructed and evaluated for accuracy according to expert recommendations; hence, it may exhibit some human bias.

Following the limitations, the work may guide researchers to include a multi-national expert group to investigate the obstacles and facilitators of IR 4.0 adoption in global contexts. Studies may examine the specific economic, environmental and social aspects of IR 4.0 adoption in the ready-made garment sector and analogous sectors and distinguish them logically with the help of MCDM models. Finally, our study may contribute to the sustained success of the T&A industry by illuminating the significant obstacles hindering the widespread adoption of Industry 4.0 in developing nations.

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Supplementary material

The supplementary material for this article can be found online.

Corresponding author

Md. Nurun Nabi can be contacted at: nurunnabimgt@gmail.com