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Exploring the Challenges of Industry 4.0 Adoption in the FMCG Sector: Implications for Resilient Supply Chain in Emerging Economy

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Abstract: *Background:* Fast-moving consumer goods (FMCG) supply chains are experiencing various challenges due to the interactions between consumers and decision-makers during physical distribution, manufacturing, wholesale and retail. One possible strategy to address these challenges for smoothing the supply chain (SC) and logistics operations is to adopt Industry 4.0 (I4.0) based technologies in the FMCG business processes. In this regard, digitalization and automation of the FMCG supply chain can be strengthened by the alluring properties of I4.0 technologies. *Methods:* This study identified nine significant challenges through a literature review and expert validation. Later, the challenges were evaluated using a novel multicriteria decision-making (MCDM) framework, the Bayesian best worst method (BWM). *Results:* The findings indicated that "requirement for substantial investment and resources", "incompatible technological infrastructure" and "poorly structured value chain" are the most significant challenges to implementing I4.0 in the FMCG industry. *Conclusions:* The study is expected to significantly contribute to improving the FMCG supply chain's resilience, sustainability, visibility, traceability and responsiveness. Additionally, the research can provide industrial practitioners valuable insights into implementing I4.0 in FMCG and similar sectors and thus promote SC sustainability and resilience in those industries.

Keywords: supply chain; FMCG business; Industry 4.0; multicriteria decision-making (MCDM); Bayesian best worst method (BWM)

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1. Introduction

Fast-moving consumer goods (FMCG) are inexpensive commodities that are sold quickly and that have a limited shelf life. FMCG includes items such as food and beverages, cosmetics, over-the-counter drugs, toiletries and other consumables. FMCG products are nondurable goods consumed relatively quickly due to their high demand and short shelf life [1]. In addition, they are frequently bought, used up quickly and sold in vast quantities. FMCG companies concentrate their marketing efforts on convincing and attracting customers to acquire their products. Price plays a significant role here and brand loyalty considerably influences consumer choices [2]. Effective marketing and product quality can build strong brand loyalty in the FMCG sector [3]. FMCG companies often invest heavily in advertising and promotion to create brand awareness and influence consumer choices. In addition to providing customers with information and sales incentives, they often run on low profit margins and rely on high sales volumes to stay in business. Hence, FMCG firms need to remain highly responsive and resilient to market demands, trends and consumer preferences to survive in a highly competitive market [4]. The complexity of FMCG logistics arises from the need to handle high volumes, diverse products, stringent timelines and varying demand patterns, all while ensuring product quality, compliance and cost-effectiveness throughout the supply chain. Due to global economic depletion, the FMCG business environment is uncertain, volatile, ambiguous and complex in emerging economies [5]. As a result, the FMCG manufacturing sector must take the required actions to ensure their survival. In today's unpredictable business, FMCG organizations must satisfy expanding customer expectations toward customized products and meet increasing demand for ecologically sustainable and economically efficient products [6]. In such a scenario, Industry 4.0 (I4.0) has recently emerged as a viable option with significant implications for manufacturing competitiveness, resilience and sustainability through digital advancement [7,8].

An increase in automation and data communication is a hallmark of the fourth industrial revolution [9]. I4.0 is a brand-new economic frontier that has the potential to have an impact on numerous FMCG businesses with a change in how products are made, sold and maintained [10]. Moreover, the idea of "smart manufacturing" is changing from the straightforward digitization and automation of individual machines to the connection of machines utilizing I4.0 technologies. Industries need to implement digitalization in their logistics processes to cope with the present industrial landscape, which is moving from mass production to personalized ways of production [11]. To boost production and efficiency in the FMCG business, I4.0 connects the digital and physical worlds via cyber–physical elements and human–machine interfaces, turning the conventional supply chain and logistics service into a smart one. By leveraging advanced smart and digital technologies, data analytics and automation, I4.0 initiatives contribute to making FMCG supply chains more agile, adaptive and capable of withstanding disruptions [12]. Thus, supply chains should be more flexible, resilient and sustainable through complete digitalization and automation of FMCG operations. Additionally, businesses are now making better decisions due to the growth in computational capacity. For this purpose, the development of novel production techniques and services based on the fusion of smart and digital technologies, including the Internet of Things (IoT), big data analysis (BDA), cyber–physical systems (CPS), robots, augmented and virtual reality, blockchain, artificial intelligence, etc., are required [13].

Implementing an IoT platform is one such strategy to gradually digitalize the FMCG supply chain. For example, IoT sensors and radio-frequency identification (RFID) tags provide real-time visibility of the movement of goods throughout the supply chain [14]. This visibility allows for proactive monitoring, enabling quick response to disruptions and reducing the impact on operations. In the retail industry, the time it takes to get a product from the warehouse to the shelf must be compared to the price [15]. This relates to the ability of adaptable companies to generate profits in a competitive market. Businesses today focus on how effectively they can introduce their products to the market despite any unplanned environmental disturbances by considering the associated costs. Machine learning algorithms assist in advanced data analytics to analyze vast amounts of data from different sources, including weather patterns, historical sales data and social media trends [16]. Predictive analytics help forecast demand accurately, allowing FMCG companies to adjust production, logistics priority support and inventory levels according to market demand fluctuations, thereby reducing excess inventory and stockouts.

Industrial production systems in FMCG have generated enormous amounts of data, which is only likely to increase due to the large product variety [17]. BDA processes massive amounts of data, such as customer behavior, sales patterns and supply chain and logistics operations [18]. Analysis of this big data provides valuable insights for demand forecasting, inventory optimization and decision-making, enabling FMCG companies to respond to market trends effectively. Blockchain creates a secure, transparent and tamper-proof ledger of transactions and events [19]. In the FMCG supply chain, blockchain can be employed to trace the origins of products, ensuring authenticity, quality and compliance with regulations [20]. It enhances transparency and trust among supply chain partners. Robotic solutions have been viewed as a way for FMCG businesses to boost their flexibility [21]. Robots are capable of excellent repeatability and accuracy and they are not affected by environmental factors like harsh temperatures or light exposure, nor do they experience ergonomic and tiredness problems like human operators [22]. Therefore, robots are employed to accomplish repetitive tasks such as packaging, palletizing, warehousing, product customization and food handling. Moreover, augmented reality (AR) and virtual reality (VR) are used in training, maintenance and visualization tasks. In the FMCG sector, they can be used for the virtual training of employees, allowing them to simulate various scenarios and learn about product handling, warehouse management and other tasks [23]. Moreover, digital twins can model production lines, warehouses and transportation networks in the FMCG supply chain [24]. FMCG companies can optimize operations through data-driven decisions by simulating and analyzing different scenarios. Thus, I4.0 technologies play a significant role in different FMCG industry operations by enhancing market resilience.

Resilience is typically defined as a global supply chain's capacity to foresee, reorganize and continuously perform its primary function despite the effects of external and internal shocks on the system [25]. Therefore, resilience is a good quality trait, especially when handling upheavals [26]. Redundancy and efficiency trade-offs must be made when designing a supply chain for resilience. I4.0 technologies optimize the entire supply chain, from raw materials sourcing to delivering finished products with logistics support [27]. Data-driven insights help choose the best suppliers, transportation routes and distribution centers. This optimization increases the efficiency of the supply chain, making it more resilient against disruptions. I4.0 enables the creation of collaborative platforms where all supply chain stakeholders, including suppliers, distributors, manufacturers and retailers, can share real-time information [28]. Collaborative platforms enhance communication, coordination and decision-making for faster responses to disruptions and better risk management. Therefore, incorporating the I4.0 technologies into FMCG supply chains improves operational efficiency and adaptability to disruptions swiftly.

Numerous studies have been undertaken to show how crucial it is to integrate IoT [29], blockchain [30], machine learning [31], BDA [32] and digital twins [33] into supply chain management. These include increased product placement security, safety and sustainability; increased chain profitability and productivity; visibility of stocks and real-time data collection; increased physical distribution transparency available to the entire supply chain; more effective control of storage conditions; and prompt response to market for meeting the need of end-user [34]. Therefore, FMCG supply chains must digitize their business processes, adopt contemporary technologies and improve their competitive position in the global market to survive in the highly competitive industrial environment. However, it is evident that no FMCG industry embraces the deployment of the I4.0 technologies in full swing in the emerging economy to achieve supply chain resilience. The present study will cover the following research questions (RQs) to determine the underlying reason for this issue:

RQ1: What challenges impede the seamless integration of I4.0 in the FMCG sector of an emerging economy?

RQ2: How can these challenges be prioritized to enhance supply chain resilience?

RQ3: What benefits do the identified challenges offer the FMCG industry in achieving supply chain resilience?

This study proposes the following specific research objectives (ROs) to address the RQs:

RO1: Identify the challenges in adopting I4.0 in the emerging economy's FMCG industry using an integrated approach.

RO2: Systematically prioritize these challenges, creating an MCDM framework highlighting their significance in shaping I4.0 adoption.

RO3: Provide decision-makers and managers with insights to formulate effective strategies for adopting I4.0 in the FMCG sector to enhance supply chain resilience.

The study applies the Bayesian best-worst method (BWM), a probability-based multi-criteria decision-making technique, to achieve the research objectives. The Bayesian BWM is a reliable multicriteria decision-making method for calculating criteria weight factors [35]. After aggregating the individual comparison pairings, information gaps may emerge in several instances of real-world multicriteria assessment scenarios where several factors concurrently impact decision-making [36]. In such instances, the Bayesian BWM means choosing one best and one worst criterion from a set of observed criteria by solving the information gap issue by acting as a group inside the observed criteria. While conventional linear BWM relies on an individual expert's judgment for determining the weights of various factors [37], the Bayesian BWM applies a statistical estimation-based technique under a probabilistic environment to allow collective or group decision-making without information loss [38]. As a result, the Bayesian BWM has overcome traditional linear BWM constraints by incorporating feedback from various experts to produce a set of appropriate group weights for more accurate assessment [39]. The Bayesian BWM has substantial advantages over other separate pairwise comparison-based MCDM approaches, such as the analytic hierarchical process (AHP) and the analytic network process (ANP). Compared to the AHP and ANP, the Bayesian BWM produces a more reliable expert opinion and requires fewer pairwise comparisons [40]. Furthermore, the Bayesian BWM reduces the possibility of making wrong decisions while comparing pairs of criteria, enhancing the reliability of the results [41].

1.1. Related Studies, Research Gaps and Contribution

Adopting I4.0-enabling technologies tends to improve the performance of the entire supply chain, particularly in procurement, manufacturing, inventory management and trading, while also advancing the ideas of information sharing, digitization automation and transparency throughout the supply network [42]. I4.0 and digital transformation have the potential to create a fully digital supply chain by increasing transparency and centralizing operations [43]. For example, Končar et al. (2020) [44] analyzed the setbacks for sustainability and the business process of the FMCG supply chain through the implementation of IoT by applying research hypotheses and finding out that financial incentives, incentives for employment and security measures are most significant. Similarly, Nozari et al. (2022) [45] evaluated the challenges of implementing Artificial Intelligence of Things (AIoT) to achieve a smart supply chain in the FMCG industry using a fuzzy decision-making trial and evaluation laboratory (DEMATEL). The study revealed that cybersecurity, a lack of proper infrastructure and a lack of professionals are the most significant challenges. However, both studies concentrated on a particular technology for implementation in the supply chain.

Madhavi and Wickramarachchi (2021) [46] reviewed the literature systematically to determine the impact of optimal decision-making to build up supply chain resilience during the COVID-19 pandemic. The study recommended applying quantitative models as most published work focuses on conceptualizing a restricted number of resilience factors. However, the quantitative models require incredibly precise tools and many respondents to develop the model, which is challenging for large industries such as FMCG. Prashar (2022) [47] applied grey-DEMATEL to envisage the complex causal relationships among the drivers of supply chain sustainability of the FMCG industry from an Indian perspective. The study disclosed that competitive pressure, regulatory and legislative pressure and innovativeness drive the implementation of supply chain sustainability practices. However, the study cannot speculate on the absolute degree of relations among the drivers. Asgharizadeh et al. (2023) [48] applied the nondominated sorting genetic algorithm (NSGA II), multiobjective grey wolf optimizer (MOGWO) and multiobjective ant lion optimizer (MOALO) to design the supply chain network model of FMCG industry during COVID-19. The study suggests adopting strategic and tactical decisions to maintain the freshness of products and reduce costs. However, the study does not indicate how supply chain resilience can help to serve the purpose. Khayer et al. (2023) [49] formulated a mixed-integer linear programming (MILP) model to adjust strategies for FMCG supply chains in Bangladesh to counter future pandemic disruptions. The key performance indicator (KPI) scores for manufacturing, procurement and distribution were significant. However, the study does not recommend improving the supply chain performance by improving those significant KPIs.

Creazza et al. (2022) [50] applied the one-way analysis of variance to appraise the perceptions of the FMCG cyber supply chain and suggest the key elements for improving cyber resilience in the FMCG supply chain. Moreover, Kamakela et al. (2023) [51] evaluated digital technology and analytics for risk management of FMCG firms in Mauritius, showing that only 29% of the firms are utilizing digital technology to predict and create visibility purposes. The study is confined to only IoT, cloud computing, AI and robotic automation technologies. However, there are more digital technologies and most of them have not been applied in the large-scale operations of the FMCG industry. Specifically, most studies on I4.0 or the digital supply chain have concentrated on the theoretical or conceptual implementation models. Nevertheless, new technological capabilities, such as smart and digital technology, have been demonstrated to improve supply chain resilience [52]. Therefore, policymakers must pick up solutions and identify the right I4.0 technologies, adopt sustainable operations management decisions, foster supply chain collaboration and establish performance enablers for modest, reachable goals.

Limited studies acknowledge the complexity of decision-making, while only some utilize formal MCDM approaches for building FMCG supply chain resilience. Most related studies focus on specific technologies like IoT or AIoT, cloud computing, AI and robotics, while neglecting a holistic view of potential I4.0 solutions. Most research explores theoretical models in real-world contexts or provides actionable recommendations. However, there are challenges as quantitative models need help acquiring necessary data, especially in large industries like FMCG. Therefore, the studies utilized established MCDM tools like DEMATEL, NSGA-II or MILP models to quantify complex decision-making scenarios. Similarly, the present study applied the Bayesian BWM in the FMCG supply chain settings. The Bayesian BWM accounts for uncertainty and subjectivity in expert opinions, which is crucial for complex decisions with limited data. It requires fewer pairwise comparisons than traditional MCDM methods, which is suitable for large industries like FMCG, where data collection might be challenging. Table 1 displays the recent literature related to the Bayesian BWM approach.

Table 1. Recent studies utilizing the Bayesian BWM approach.

Literature	Tool Used	Country	Research Area	Objectives
Gupta et al. (2023a) [53]	Bayesian BWM	India	Agri-logistics	To identify risks and the mitigating strategies
Gupta et al. (2023b) [54]	Delphi and Bayesian BWM	India	Logistics	To rank challenges to smart and sustainable logistics
Debnath et al. (2023) [55]	Bayesian BWM	Bangladesh	Pharmaceutical	To evaluate the critical success factors (CSFs) for implementing I4.0
Chauhan et al. (2022) [56]	MBAC and Bayesian BWM	India	Pharmaceutical	Socio-technological framework for selecting suppliers
Munim et al. (2022a) [57]	Bayesian BWM	Norway	Oil and gas industry	To identify and rank blockchain technology adoption
Munim et al. (2022b) [35]	Bayesian BWM	Bangladesh	Ready-made garments industry	To assess the actions taken by the export- industries during COVID-19
Abkenar et al. (2022) [58]	Bayesian BWM	N/A	Food industry	To determine the importance of barriers to IoT implementation

However, no prior research has examined long-term practices related to I4.0 adoption in FMCG supply chain resilience. Furthermore, no previous study has investigated such challenges from the standpoint of a developing economy utilizing a Bayesian best-worst method framework. As a result, the originality of this proposed research resides in combining the ideas of I4.0, resilience, emerging economies and a Bayesian-BWM-based MCDM framework with the FMCG business, which has never been performed before. This research aims to address a gap in the literature by offering the following research contributions:

1.2. Theoretical Contributions

- To propose the conceptual probabilistic framework of the Bayesian-BWM-based structure for ranking and evaluating the identified challenges with their implications.
- To construct the connection between FMCG supply chain resilience, I4.0 technologies and emerging economy.
- To promote a theoretical pathway for I4.0 adoption to incorporate sustainability and resilience together in the FMCG supply chain of the emerging economy.

1.3. Practical Contributions

- To pinpoint the challenges to adopting I4.0 in the FMCG industry of an emerging economy like Bangladesh.
- To guide the policymakers, industry leaders and managers with crucial insights to make strategic action plans and decisions for implementing I4.0 in the FMCG industry while ensuring resilience in the supply chain of this sector.

This study's novelty lies in applying the Bayesian BWM conceptual framework to assess the critical challenges of adopting I4.0 in the FMCG industry from an emerging economy context. There is a lack of study on the adoption of I4.0 in the FMCG sector of any emerging economy. In this study, the Bayesian probabilistic approach applied posterior distribution to reduce the uncertainty by providing inferences with small data. The outcome of this study can help industrial practitioners and managers solve the potential challenges of integrating I4.0 to achieve supply chain resilience in the FMCG sector. This specific focus makes the research highly relevant and timely, given the growing interest in sustainable and resilient supply chains. Thus, the research fills a gap in the existing literature by focusing on I4.0 adoption in the FMCG sector to improve its resilience.

The remainder of this article is structured as follows: Section 2 details the Bayesian BWM approach's survey design procedure, data collection and methodological details. The findings are then reported in Sections 3 and 4, which discuss the findings. Section 5 discusses the study's implications. Finally, Section 6 brings the study to a conclusion.

1.4. Key Challenges to Adopting I4.0 for the FMCG Supply Chain Resilience

Several studies have investigated the significant factors, barriers and critical success factors (CSFs) to achieve I4.0 in diffusing over various sectors in recent years. Therefore, a complete investigation of the relevant articles using the Scopus and Google Scholar databases between the period of 2021 to 2023 and a list of ten (10) relevant challenges are formulated to promote I4.0 in FMCG supply chain resilience. This first list of challenges from resources in the literature was distributed to the experts to validate the primarily identified challenges shown in Table A1 of Appendix A. The COVID-19 pandemic in 2020 significantly affected global supply chains and highlighted the need for increased resilience and adaptability [59]. This led to a surge in I4.0 adoption across various sectors, including FMCG, as companies sought to automate processes, improve visibility and optimize operations. The year 2021 was marked as a pivotal year in this acceleration, with many companies investing in key technologies like IoT, AI and cloud computing [60]. In 2021–2023, there was a growing body of academic research on the adoption of I4.0 in various sectors, including the FMCG sector [61]. This provided a strong foundation to draw upon and contribute to the study. Therefore, by focusing on 2021–2023, the study could capture the latest trends and challenges in I4.0 adoption within the FMCG sector, including the initial implementation phase and ongoing hurdles faced by FMCG companies.

By examining the study's relevance, the experts deleted two challenges ("Traditional organizational structure" and "Complexity in emerging technical equipment mobilization") and introduced one new challenge ("Poorly structured value chain"). Finally, Table 2 shows the finalized challenges related to I4.0 adoption in the FMCG sector for supply chain resilience and how they affect such efforts.

Table 2. Finalized list of challenges for adopting I4.0 for supply chain resilience in the FMCG industry.

Code	Challenge's Name	How Does the Challenge Affect the Implementation of I4.0 in FMCG Industries?	Sources
C1	Incompatible technological infrastructure	Incompatible technological infrastructure may lack interoperability, create cybersecurity risks, produce inconsistent data and lack scalability, making it difficult for different supply chain components to communicate effectively.	[62]
C2	Unwillingness to adopt changes	Most of the FMCG industry uses obsolete technology and most senior management hesitates to change since they are unaware of I4.0's technological developments. As a result, their reluctance to change might result in restricted visibility, making it difficult to spot bottlenecks, precisely manage inventory levels or determine the cause of quality concerns, negatively compromising supply chain resilience.	[63]
C3	Poorly structured value chain	Poor value chain structure creates a lack of performance among the supply chain entities such as suppliers, manufacturers, logistics providers and retailers, which impedes supply chain capabilities and management during the service to satisfy consumers' shifts in preference.	Expert Feedback
C4	Lack of highly skilled human resources	A shortage of skilled personnel hinders innovation and can lead to improper implementation of the I4.0 technologies, resulting in inefficiencies, data inaccuracies and suboptimal use of advanced tools. Identifying and fixing technical issues becomes slower and less efficient in the absence of highly experienced human personnel, resulting in lengthier downtimes and diminished supply chain agility.	[64]
C5	Requirement for substantial investment and resources	Implementing I4.0 technologies requires significant upfront investment in hardware, software, training and infrastructure upgrades. Moreover, transitioning to I4.0 may require temporary halts or slowdowns in production and distribution processes, impacting the continuity of the supply chain.	[65]
C6	Uncertain profitability in digital infrastructure	FMCG companies may be hesitant to invest in I4.0 technologies if the profitability of these digital infrastructure upgrades is uncertain. The possibility of misallocating smart and digital infrastructure resources generates financial uncertainty among FMCG firms without a clear grasp of profitability.	[66]
C7	Ineffective technological transformation management	I4.0 technology is fundamentally challenging to manage since it changes frequently and unpredictably. The necessary qualified labor to implement I4.0 technologies cannot be produced due to a lack of digital literacy. Because of this, the production process cannot cope with automated production processes, thus hampering increasing output with increased expenditures.	[67]
C8	Lack of auspicious government support and regulations	Government support is vital for research and development (R&D) activities related to I4.0. FMCG industries may face interoperability, hinder the seamless exchange of data and information and technology integration in the absence of standardized frameworks for I4.0 technologies, leading to fragmented implementation efforts across the supply chain and thus, affecting resilience.	[68]
C9	Complexity in managing database system	It is challenging to accomplish connection and interoperability with numerous devices, processes, sensors and products, as well as the capacity to glean relevant information from a multitude of data.	[69]

2. Methodology

2.1. Study Context

The FMCG industry in Bangladesh can satisfy international and domestic customer demand. Over the last decade, the nation's expenditure on FMCG consumers has increased both in rural and urban areas and demand is shifting from urban to rural regions [70]. The FMCG sector in Bangladesh is diverse, encompassing a wide range of products including food and beverages like snacks, dairy products and packaged foods. The personal care segment covers soaps, shampoos, cosmetics and hygiene products. Household products like detergents, cleaning agents and kitchen essentials also comprise the FMCG market. FMCG industries include dairy products, frozen foods, biscuits, etc.; household products like cleaning and toiletries; beverage products such as frozen food, juice, coffee and biscuits; self-care products, footwear, eyewear, toys, pet care, counter medication, etc. [71]. Compared to luxury products and other commodities, the FMCG business has remained comparatively stable, with food and drink, personal care and household care serving as the sector's development pillars [49].

The nation's growing living standards have expanded with the support of some giants in FMCG industries. Among them, Unilever, 187, Shanta Forum, 188/B Bir Uttam Mir Shawkat Sarak, Dhaka 1208, Bangladesh offers a wide range of products in Bangladesh, including personal care items like soap, shampoo and skincare products (e.g., Lux, Dove, Fair & Lovely, as well as food and beverage products like tea and ice cream (e.g., Lipton, Walls) [72]. Procter & Gamble (P&G), Concord Bilkis Tower, 40/6 Madani Ave, Dhaka 1212, Bangladesh produces various personal care and household products. Brands such as Head & Shoulders, Pantene, Gillette and Pampers are part of their product lineup [73]. Nestlé, 227/A, Level#4, Ninakabbo, Dhaka 1208, Bangladesh offers a diverse range of food and beverage products, including dairy products (e.g., Nestlé Milkpak), cereals (e.g., Koko Krunch) and coffee (e.g., Nescafé) [74]. Square Consumer Products Limited, 48, Mohakhali CA, Dhaka 1212, Bangladesh manufactures and markets various products, including pharmaceuticals, toiletries, health and hygiene products and food items (e.g., Square Toiletries, Square Food & Beverage) [75]. Renata Limited, Plot-1, Milk Vita Road, Dhaka 1216, Bangladesh produces various FMCG products, including pharmaceuticals, animal health products and consumer health products (e.g., Sohoz, an affordable hygiene and personal care brand). ACI Limited, ACI Centre 245, Tejgaon Industrial Area, Dhaka-1208, Bangladesh produces and markets various products, including food items, personal care products and home care solutions (e.g., ACI Pure, Savlon) [76]. Bashundhara Group, plot 125/a Rd 2 Block A, Khilkhet TSO, Dhaka 1229, Bangladesh is one of the largest industrial conglomerates in Bangladesh, with a presence in FMCG through their production of edible oils, toiletries and tissue products (e.g., Bashundhara Tissue, Bashundhara Edible Oil) [77]. Keya Group, Jarun, Konabari, Gazipur, Dhaka, Bangladesh is known for its spices, edible oil and other food products. They offer a range of food items, including spices, snacks and edible oils, under various brand names like “Keya”, “Well” and “Tulip” [78].

In such a scenario, the FMCG industry has a significant potential to contribute to the country's GDP growth, which may be further increased by embracing digitization and sustainability. For this purpose, the People's Republic of Bangladesh has increased its investment in the prominent sector, which was USD 14 billion during 2016–2020 and approximately USD 40 billion during 2021–2025 [79]. Bangladesh achieved a net revenue of USD 13,685.44 million during July–September of the fiscal year 2023–2024 only. The FMCG product export summary during the July–September month of the fiscal year 2023–2024 is illustrated in Figure 1.

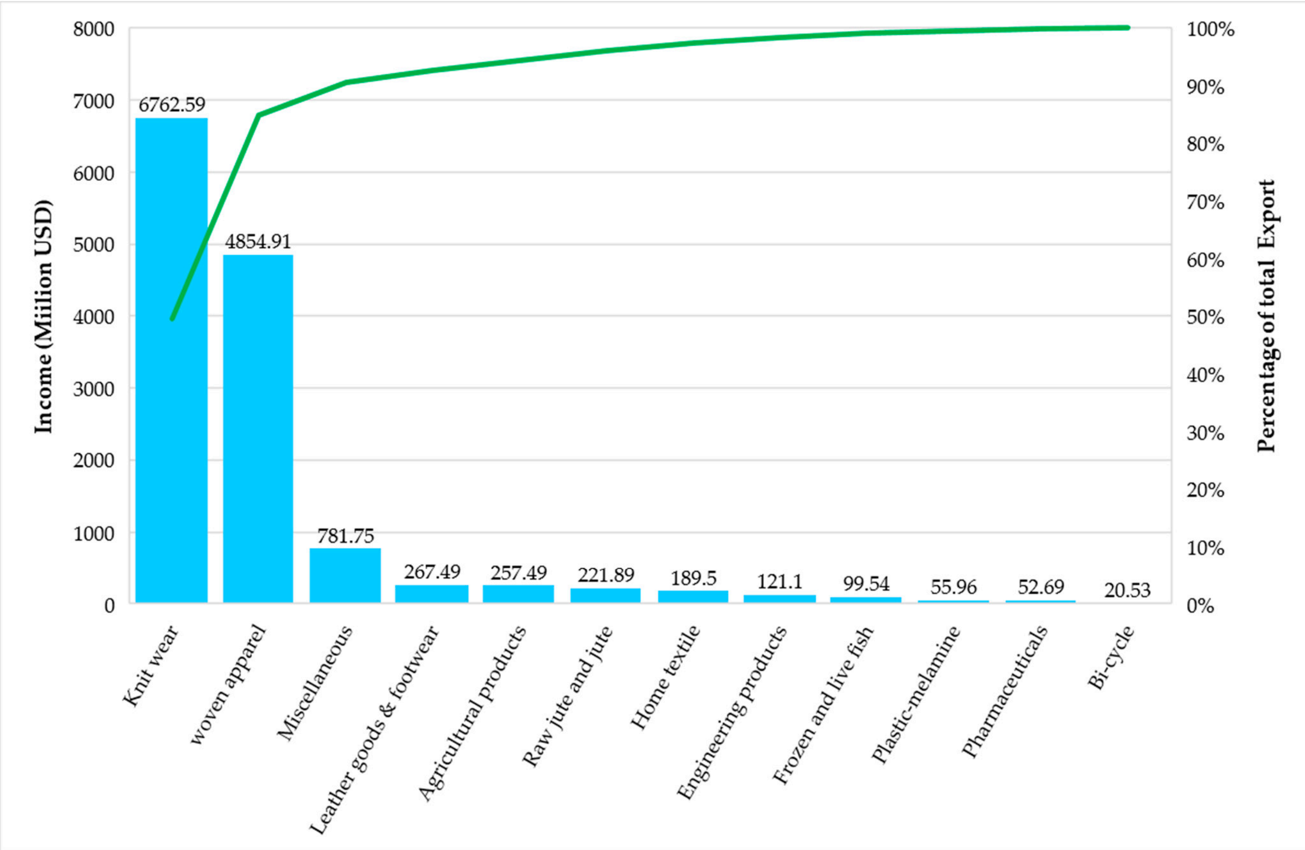

Figure 1. FMCG products export scenario of July–September of 2023–24 fiscal year (data extracted from EPB [80]).

2.2. Survey Design and Data Collection

The survey work was divided into two phases in this study. Firstly, using the snowballing technique, the challenges that impede the adoption of I4.0 to facilitate a resilient supply chain in the FMCG industry were discovered from the existing literature [55]. With a timeline of 2021–2023, the factors were searched in the Google Scholar and Scopus databases. A research methodology was constructed throughout the literature review and the snowball technique [81] included searching databases, key terms, inclusion and exclusion criteria and a study timeframe, as shown in Table 3. This extensive literature review initially discovered more than 80 papers with key phrases. However, only the 28 most relevant articles, projects and reports were eventually assessed to fulfill the RQs following a comprehensive full-text screening and execution of the study technique.

Therefore, following the research protocol mentioned above, ten (10) challenges to I4.0 adoption in emerging economies were identified initially. The respondents who were chosen were actively involved in the FMCG industry. The experts were picked for their breadth of knowledge in supply chain, operations, logistics, procurement and quality assurance and their more than six years of relevant industry experience. The decision experts (DEs) were chosen using the purposive sampling technique [81]. The purposeful sampling method is appropriate for selecting experts for a specific evaluation to achieve the study's goal [82]. The survey was conducted both digitally and in person. For this investigation, 18 experts in the FMCG sector were initially approached. However, 12 experts (67.67%) consented to participate in the survey (factor validation and factor analysis). Twelve (12) industry leaders in each field were questioned to identify and aggregate the key elements for further inquiry [55]. The overall profile of the 12 responding experts is shown in Table 4.

Table 3. Applied research protocol for conducting the systematic literature review.

Protocol Applied	Brief Description
Databases	Scopus and Google Scholar
Language	English
Timeline	2021 to 2023
Search Keywords	"Challenges" OR "impediments" OR "barriers" AND "FMCG" OR "Fast moving consumer goods" AND "I4.0" OR "challenges and I4.0" OR "barriers of I4.0 adoption" AND "supply chain" OR "logistics"
Inclusion criteria	(i) Scientific articles emphasizing the potential, factors or impact of I4.0 adoption in FMCG; (ii) Articles related to the RQs and ROs
Exclusion criteria	(i) Articles lacking in information and methodological rigor; (ii) Ineffective articles that do not respond to the specific RQs or research design; (iii) Unindexed research publications in Scopus, Web of Science, or Google Scholar
Data extraction	The selected challenges were significant to I4.0 adoption to facilitate a resilient supply chain and logistics from an emerging economy perspective.

Table 4. An overview of the experts' profiles.

Experts	Educational Background	Expertise Area	Experience (Years)
Expert 1	M.Sc. in Procurement and Supply Management	Procurement	12
Expert 2	M.Sc. in Supply Chain and Logistics	Logistics	14
Expert 3	M.Engg. in Advanced Engineering Management	Demand Planning	10
Expert 4	M.Sc. in Supply Chain Management	Supply Chain	16
Expert 5	B.Sc. in Electrical and Electronics Engineering	Digital Transformation Analyst	5
Expert 6	Ph.D. in Industrial and Production engineering	Decision Analysis	8
Expert 7	B.Sc. in Computer Science and Engineering	Information and Communication	7
Expert 8	B.Sc. in Robotics and Mechatronics Engineering	Automation and Technological Advancement	6
Expert 9	Ph.D. in Industrial Engineering Management	Research Scholar	10
Expert 10	B.Sc. in Industrial and Production engineering	Planning and Operations	11
Expert 11	M. Sc. in Data Science	Research & Development in I4.0	9
Expert 12	M.Sc. in Supply Chain and Logistics	Supply Chain	13

Regarding the validity of the relevance of the associated challenge, the expert's responses were obtained in a "yes" or "no" style. Following the expert's feedback, the "no" response was regarded as "0", while the "yes" response was regarded as "1". The arithmetic average for each task was then determined and the challenge with a feedback average score that exceeded 0.7 was chosen for further investigation.

Following the identification of the final nine (9) challenges in Table 1, twelve (12) experts from the challenge's validation phase were invited again to participate in the Bayesian BWM analysis survey. For the experts' convenience, the survey was conducted online using Google Forms. The "Best to Others" and "Others to Worst" matrices were constructed based on expert responses for Bayesian BWM analysis. Figure 2 illustrates the methodological framework followed in this study.

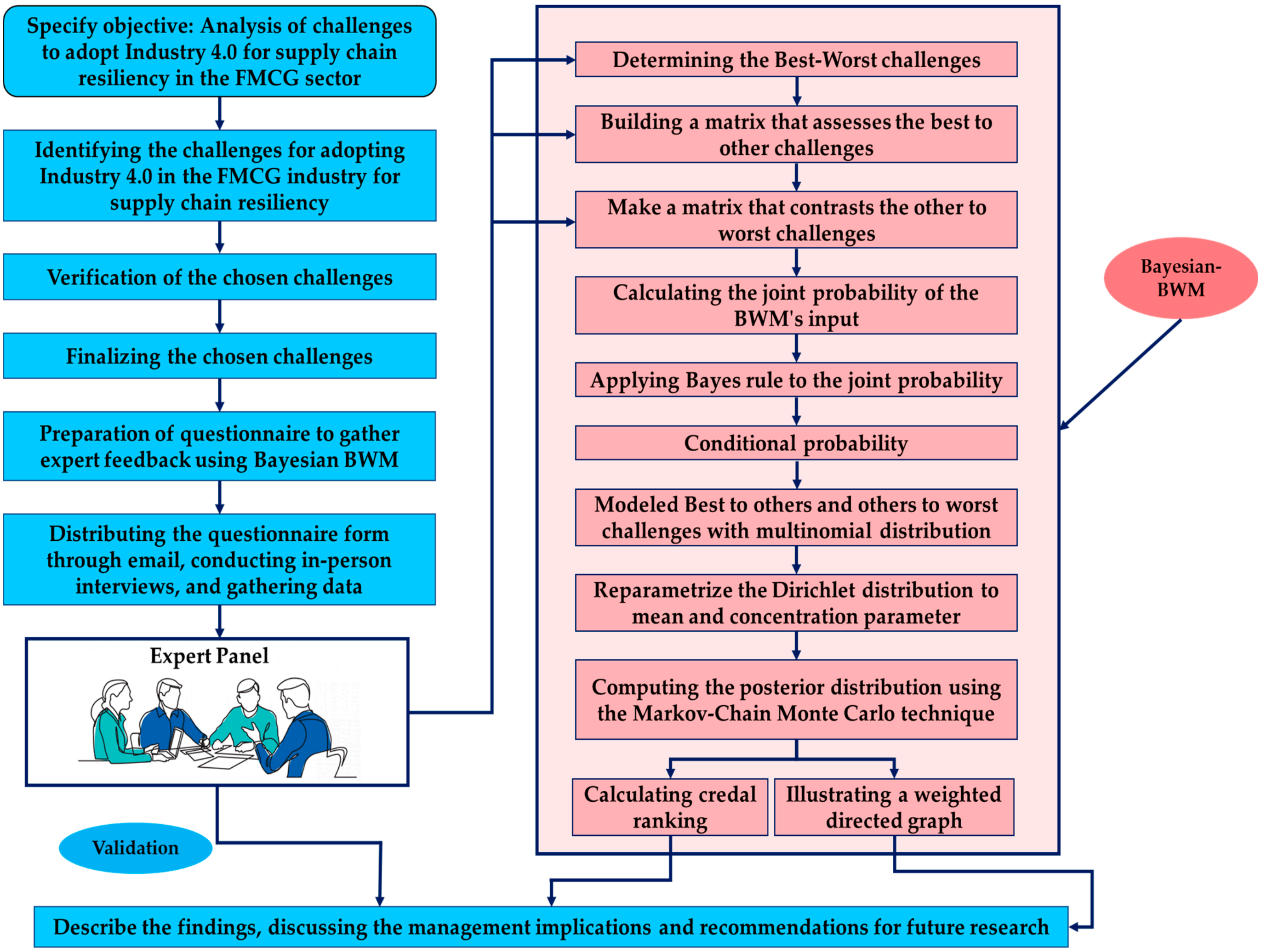

Figure 2. Proposed conceptual framework for Bayesian best-worst method (BWM).

2.3. Baysian Best-Worst Method

A multicriteria decision-making method called the "Best-Worst Method" (BWM) determines the appropriate weights for a collection of criteria based solely on the preferences of one decision-maker (DM). The Bayesian best-worst method, a modified and revised edition of the BWM for group decision-making, is an MCDM methodology in which the opinions of various experts are aggregated, applying a probabilistic approach to enable more accurate decision-making regarding the integrated ranking of the criteria under consideration [83]. The Bayesian BWM is stochastic since comparisons are accomplished pairwise by applying the multinomial distribution and the Dirichlet distribution is utilized to compute global weights [84]. The main advantage of the Bayesian BWM is that it decreases inconsistency in the comparison data more than traditional BWM [85]. Recently, the Bayesian BWM technique has been used in research across various industries, such as ready-made garments, furniture, telecommunication, healthcare, sports and tourism and the oil and gas industry.

For example, take a group of challenges, $C = \{C_1, C_2,\ C_3,\ \ldots\ldots\ldots.,\ C_s\}$, which are assessed by x experts. The key steps of the Bayesian BWM [35,86] are described below:

1. Selection of the best and worst challenge: Each expert, x, must select just one best $\left(C_B^x\right)$ and worst $\left(C_W^x\right)$ challenge from the group of challenges. Without doing any pairwise comparison, the experts are simply determining the best and worst challenge in this phase. Therefore, the best challenge is the most significant challenge and the

worst challenge is the least significant challenge according to the choice of x experts. Thus, various experts may select distinct challenges as their best or worst.

2. Generating best to others pairwise comparison: A pairwise comparison matrix for the best challenge $\left(C_B^x\right)$ is created from the set of C and other challenges by x expert. Then, each expert selects a value between "1" and "9" to indicate their choice for representing the best challenges over the other challenge in C as mentioned in Step 1. Here, "9" means $\left(C_B^x\right)$ is much more significant than the other challenge, while "1" denotes the challenge is equally significant. Thus, the x expert results in the collection of pairwise comparison matrix "Best-to-Others", which is denoted by O_B^x, in Equation (1).

$$O_B^x = (o_{B1}^x, o_{B2}^x, \ldots\ldots\ldots\ldots\ldots\ldots\ldots.., o_{Bx}^x); x = 1, 2, 3, \ldots\ldots\ldots\ldots\ldots\ldots., X \tag{1}$$

where o_{Bj}^x is denoted as the preferred challenge of experts x' for the best challenge $\left(C_B^x\right)$ over $c_j \in C$.

Table A2, Appendix B displays the "Best-to-Others" matrix from each expert feedback in this study.

3. Developing the others to worst pairwise comparison: Similarly, a pairwise comparison matrix for the worst challenge $\left(C_W^x\right)$ is created from the set of C and other challenges by x expert. The x expert creates the collection of the pairwise comparison matrix "Others-to-Worst", which is denoted by O_W^x, in Equation (2).

$$O_W^x = (O_{1W}^x, O_{2W}^x, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, O_{xW}^x)^T \tag{2}$$

where o_{JW}^x is denoted as the preferred challenge of experts x for the worst challenge $\left(C_W^x\right)$ over $c_j \in C$.

The "Others-to-worst" matrix for each expert in this study has been shown in Table A3, Appendix C.

4. Calculating aggregated weight and individual optimal weight: The aggregated optimal weight k^{agg} and each optimal weight $k^{1:X}$ for given $O_B^{1:X}$ and $O_W^{1:X}$ are calculated. The individual probability and joint probability distribution for each challenge are computed by Equations (3) and (4), respectively.

$$P(u) = \sum_v P(\alpha, \beta) \tag{3}$$

$$P\left(k^{agg}, k^{1:X} \middle| O_B^{1:X}, O_W^{1:X}\right) \tag{4}$$

Here, α and β represent arbitrary random variables.

5. Bayesian probabilistic hierarchical model: Let us consider that all the independence of different variables, Bayes' rule and Equation (4) combination result in Equation (5).

$$\begin{aligned} P\left(k^{agg}, k^{1:X} \middle| O_B^{1:X}, O_W^{1:X}\right) &\propto P\left(O_B^{1:X}, O_W^{1:X} \middle| k^{agg}, k^{1:X}\right) P\left(k^{agg}, k^{1:X}\right) \\ &= P(k^{agg}) \prod_{X=1}^{X} P\left(O_W^X \middle| k^X\right) P\left(O_B^X \middle| k^X\right) P\left(k^X \middle| k^{agg}\right) \end{aligned} \tag{5}$$

The probability chain rule, conditional independence of distinct variables and the expert's separate judgments on each challenge are used to construct the last equality. All variables must be defined before computing the posterior distribution because all variables, in this case, are integers, they may be described by a multinomial distribution. Because the two matrices (O_B^X and O_W^X) are exactly the opposite and reverse weight is obtained.

$$O_B^X \middle| k^X \sim multinomial\left(\frac{1}{k^X}\right) \tag{6}$$

$$O_W^X \Big| k^X \sim multinomial\left(\frac{1}{k^X}\right) \tag{7}$$

Then, aggregated weights $\left(k^{agg} = k_1^*, k_2^*, \ldots\ldots\ldots\ldots.., k_p^*\right)$ of all x experts and optimal weight (k^x) are calculated by the following Equations (8)–(10).

$$k^x | k^* \sim Dir(\gamma \times k^*) \tag{8}$$

$$\gamma \sim gamma(0.1, 0.1) \tag{9}$$

$$k^* \sim Dir(1) \tag{10}$$

Here, Dir is a Dirichlet distribution, while $gamma$ $(0.1,\ 0.1)$ is a gamma distribution with form parameters of 0.1. The probabilistic model of the Equation (10) provides no closed-form solution. A Markov-chain Monte Carlo (MCMC) sampling is required to compute the solution [87]. Just Another Gibb Sampler (JAGS), one of the best available probabilistic languages, was utilized to determine the solution.

The following definitions of credal order and ranking will be employed to determine the confidence level and hence develop the probabilistic hierarchical model.

Definition 1. *For a pair of challenges C_i and C_j, the credal ordering, A, can be mentioned as:*

$$A = \left(C_i, C_j, E, f\right) \tag{11}$$

Here, f is the confidence degree between the relation of the challenges and E is the relation between the challenges, C_i and C_j.

Definition 2. *A series of credal orderings is used to express the credal ranking. For a given set of challenges, $C = \{c_1, c_2,\ c_3,\ \ldots\ldots\ldots.,\ c_s\}$, it includes all pairs $\left(c_i, c_j\right)$ for all c_i, $c_j \in C$. Let us consider a sample size H. The confidence score can be calculated with Equation (12) to know if c_i is superior to c_j.*

$$P\left(c_i > c_j\right) = \frac{1}{H}\sum_{h=1}^{H} I\left(k_i^{agg_h} > k_j^{aag_h}\right) \tag{12}$$

3. Results

This section displays the established ranks of challenges as determined by the framework of the Bayesian BWM. One major outcome of the Bayesian BWM is the weighted directed graph displaying credal ranking, as illustrated in Figure 3. The challenges and related average weights are denoted by the circular vertices (orange colored) of these graphs, which are determined as the mean of the aggregated weight (k^*), distribution. Each line $S \xrightarrow{q} T$ denotes S challenge is more significant than T, with a confidence score of q. Overall, the general structure of the graph incorporates the hierarchy of a collection of challenges in terms of credal ranking, where each line represents an individual credal ordering.

From Figure 3, it is found that "requirement for substantial investment and resources (C5)" is the most significant challenge, with the weight of 0.1372, to adopting I4.0 for supply chain resilience in the FMCG industry with a confidence score of 0.54 against "incompatible technological infrastructure (C1)", with a confidence score of 0.65 against "poorly structured value chain (C3)", with a confidence score of 0.88 against "lack of highly skilled human resources (C4)", with a confidence score of 0.89 against "ineffective technological transformation management (C7)" and with a confidence score above 0.95 against "complexity to manage database system (C9)", "unwillingness to adopt changes (C2)", "lack of auspicious government support and regulations (C8)" and "uncertain profitability in digital infrastructure (C6)". Nevertheless, "Incompatible technological infrastructure (C1)" is the second significant challenge with a weight of 0.135, followed by "Poorly structured value chain (C3)" in third with a weight of 0.1284. Although "requirement for substantial investment and resources (C5)" is more significant in the hierarchical credal ranking than “incompatible technological infrastructure (C1)”, even so, it is more desirable than “incompatible technological infrastructure (C1)” with a confidence score of 0.54.

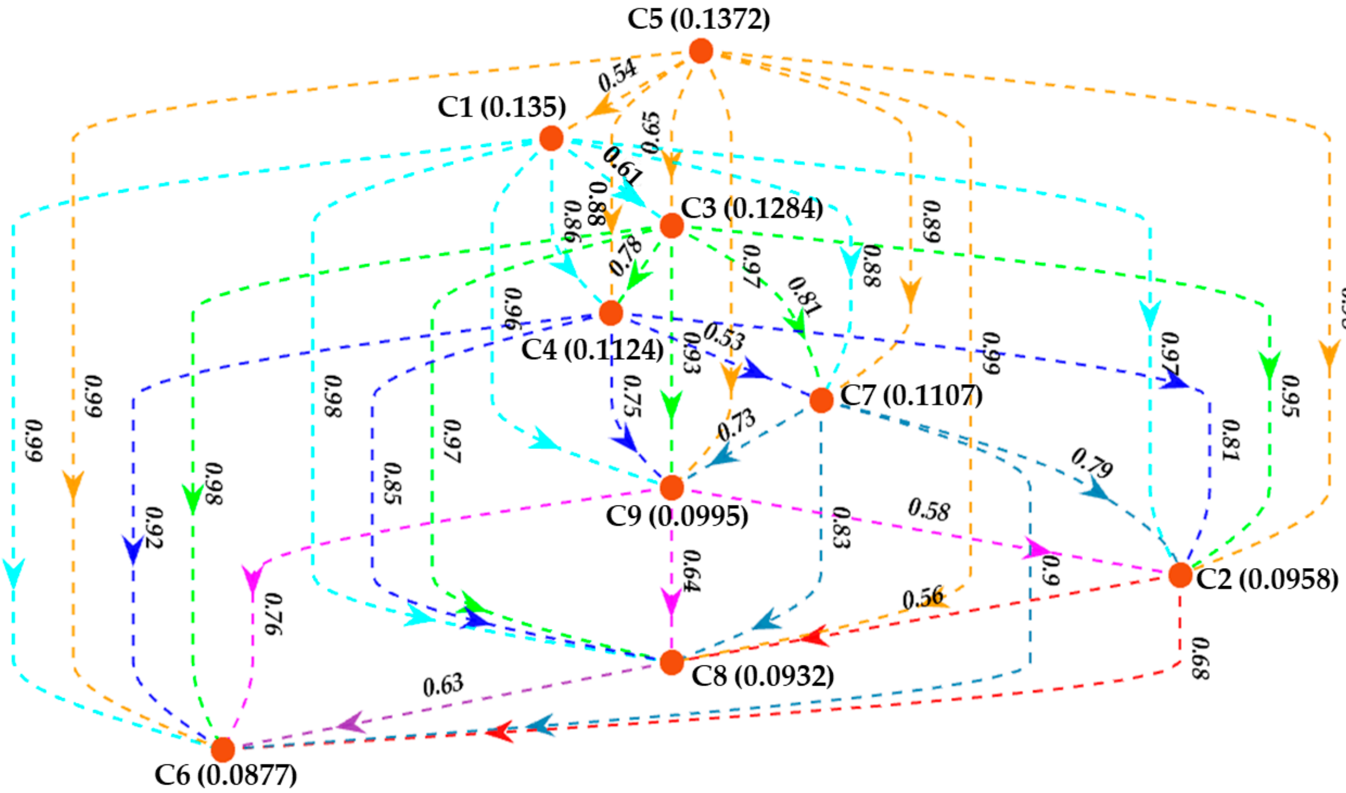

Figure 3. The hierarchical credal ranking with confidence scores for adopting I4.0 in FMCG supply chain resilience challenges. Note: Different colors and arrows denote relationship of a particular challenge with other remaining lower ranking challenges.

Conversely, “uncertain profitability in digital infrastructure (C6)” is the least significant challenge, weighing 0.0877. The study also shows that “lack of highly skilled human resources (C4)” and “Ineffective technological transformation management (C7)” are the fourth and fifth significant challenges, with weights of nearly 0.1124 and 0.1107, respectively. Therefore, policymakers must set specific strategies to overcome the “requirement for substantial investment and resources (C5)” more than other challenges since “C5” is weighted more than other challenges. However, the “requirement for substantial investment and resources (C5)” weighed nearly equal to “incompatible technological infrastructure (C1)”, implying that decision-makers need to focus on both with nearly high priority.

The numerical values assigned to the directed links signify the confidence score associated with each criterion, as shown in Figure 3. Mohammadi and Rezaei (2020) [84] also denoted the confidence score as the credal ranking. The scores denote the level of significance between the challenges to exhibit the most important relations within those challenges. For instance, a confidence score of 0.9747 between C1 and C2 suggests that the significance of C1 surpasses that of C2, whereas a confidence score of 0.6139 between C1 and C3 implies that C1 is more important than C3. The threshold confidence score can vary from problem to problem and it is entirely up to the decision experts to choose a specific threshold confidence score. For example, a confidence of 0.6 between key strategies may be sufficient for flexible and sustainable supply chain management [75]. Nevertheless, our study considered a confidence score above 0.5, which we consider to be a threshold for this study’s specific context. The confidence scores among the associated challenges are presented in Table 5.

Table 5. Confidence scores among the associated challenges.

Barrier Name	C1	C2	C3	C4	C5	C6	C7	C8	C9
Incompatible technological infrastructure	0	0.9747	0.6139	0.8572	0.4613	0.9925	0.8787	0.9824	0.9588
Unwillingness to adopt changes	0.0253	0	0.0505	0.1854	0.0213	0.6845	0.2102	0.5598	0.4154
Poorly structured value chain	0.386	0.9495	0	0.7785	0.3491	0.9832	0.8069	0.9653	0.9281
Lack of highly skilled human resource	0.1428	0.8146	0.2215	0	0.1238	0.9161	0.5346	0.8543	0.753
Requirement for substantial investment and resources	0.5387	0.9787	0.6509	0.8762	0	0.9938	0.8933	0.9868	0.9673
Uncertain profitability in digital infrastructure	0.0075	0.3155	0.0168	0.0839	0.0062	0	0.1016	0.371	0.2448
Ineffective technological transformation management	0.1213	0.7898	0.193	0.4654	0.1067	0.8984	0	0.8346	0.7265
Lack of auspicious government support and regulations	0.0176	0.4402	0.0347	0.1456	0.0132	0.629	0.1654	0	0.3561
Complexity in managing database system	0.0412	0.5846	0.0719	0.2469	0.0327	0.7552	0.2735	0.6439	0

4. Discussion

The proposed Bayesian BWM framework indicates that the most crucial challenge of adopting I4.0 for supply chain resilience is the "requirement for substantial investment and resources (C5)", as shown in Figure 3. Although I4.0 technologies bring profitability, these are expensive for small and midsize enterprises (SMEs) in FMCG industries. I4.0 implementation involves substantial upfront costs for acquiring new technologies, upgrading existing infrastructure, purchasing IoT devices, implementing data analytics solutions and training the workforce [88]. As a result, the lack of substantial investment is a significant challenge that hinders FMCG SMEs from integrating I4.0 technologies. Moreover, FMCG companies often operate on tight budgets and face intense competition. They allocate a significant portion of their budget to technology upgrades that impact other essential areas such as marketing, logistics, product development and distribution [89]. Therefore, policymakers must balance the need for investment in I4.0 with other strategic priorities, which is also challenging. They can also develop a long-term strategic roadmap by prioritizing investments based on critical areas that require immediate improvement. In addition, FMCG companies must allocate resources for technology acquisition and train employees to use and manage these technologies effectively [90]. To prevail over the investment challenge, FMCG can begin with smaller-scale pilot projects to investigate the impact of I4.0 technologies [91]. Thus, pilot projects allow FMCG companies to test the advanced technology's feasibility, assess its benefits and understand potential challenges before committing to large-scale implementations [92]. Successful pilot projects can build confidence and justify further investments for FMCG enterprises. Moreover, FMCG companies can partner with technology providers, startups and research institutions that provide access to expertise, technology prototypes and innovative solutions at reduced costs.

The requirement for substantial investment becomes higher when most of the technological infrastructure of the FMCG industry is obsolete to I4.0 and the changing trends of technologies make the old technologies obsolete. Similarly, "Incompatible technological infrastructure (C1)" is the second significant challenge to I4.0 adoption for supply chain resilience in the FMCG. Technological infrastructure is the heart of the industrial revolution, preventing bottlenecks and speeding up the FMCG business process by creating shorter inventory, accomplishing on-time procurement, increasing efficiency, handling uncertainty and so on [93]. Thus, compatible technological infrastructure helps the FMCG industry to respond quickly to any disturbance and market changes, keeping the supply chain resilient. Therefore, FMCG industries need to incorporate cloud platforms, blockchain, cobot, IoT, CPS and other technical solutions. Compatible technological solutions must have characteristics such as interconnection, event management, sharing, proactive decision-making capabilities and scalability of on-demand resources. Moreover, FMCG companies can consider outsourcing integration projects to specialized firms experienced in resolving technology incompatibilities. With continuous and robust monitoring, various analytics tools can be integrated to track the performance of conventional technology, data flow and potential bottlenecks [94]. Finally, compatible technological infrastructure plays a crucial role in structuring the value chain of FMCG for I4.0 adoption.

FMCG industries invest large amounts of their revenues to become responsive to fulfill customer demand by ensuring product quality. In contrast, I4.0 technologies facilitate the integration of data from various sources across the value chain. “Poorly structured value chain (C3)” is the third significant challenge for I4.0 implementation in the FMCG for supply chain resilience. It is evident that I4.0 technologies increase the product’s value with a resilient supply chain advantage in a competitive global market. For instance, IoT RFID tags, sensors and other smart devices impart real-time data on production status, vehicle routing, inventory levels, transportation and more [95]. Moreover, IoT devices and automation solutions optimize manufacturing and logistics processes. Sensors monitor equipment performance and product quality, ensuring that production processes are efficient and products meet the required standards [96]. Digital platforms and CPS-enabled systems facilitate seamless supplier communication and collaboration [97]. Subsequently, blockchain technology, combined with IoT sensors, provides end-to-end traceability of products within the value chain. As a result, companies can provide maximum product value with minimal cost.

Consequently, the consumers become satisfied with the products and services as they become the value for money. To overcome a poorly structured value chain, FMCG industries can perform value stream mapping (VSM), applying emerging technologies in their supply chain to structure the whole value chain [98]. Moreover, lean manufacturing, supply chain transparency, diversifying technology suppliers, effective product distribution network development, optimized vehicle routing and supplier collaboration can help structure the whole value chain of FMCG for I4.0 adoption. Moreover, global FMCG industries are investing in I4.0 technologies to achieve a competitive advantage of resilient supply chains in their value chain. Awan et al. (2022) [99] also suggested rebuilding a poorly structured value chain to respond to potential FMCG industry consumers as an effective way to adopt I4.0 technology. However, a shortage of highly skilled human resources does not improve the value chain; it can hinder a business’s efficiency, productivity and overall competitiveness.

To sustain the value chain of FMCG industries, practitioners must also deal with the challenge related to the “lack of highly skilled human resources (C4)”, the fourth significant challenge according to the Bayesian BWM framework. FMCG industries in emerging economic countries lack highly skilled human resources as the I4.0 infrastructure is new in this sector and employees need training regarding the new technologies. Therefore, the employees in this sector cannot contribute successfully to technology adoption and management to increase supply chain resilience. Skilled employees can drive efficiency, innovation, adaptability and customer satisfaction, contributing to the rapid adoption of I4.0 within the FMCG industry [100]. Therefore, companies should invest in training, talent acquisition and skill development programs to ensure they have the skilled workforce necessary to enhance supply chain resilience. Skilled human resources drive innovation within companies. Without a highly skilled workforce, FMCG industries may struggle to explore new ways of leveraging I4.0 technologies for supply chain optimization [101]. It also creates barriers to innovation that hamper the industry's ability to proactively address challenges and capitalize on emerging opportunities, thereby reducing overall resilience.

Technology management can be a pathway to adopting advanced I4.0 more quickly and developing skilled personnel. However, various FMCG industry personnel failed to manage emerging technologies purposelessly, turning "ineffective technological transformation management (C7)" as the fifth significant challenge. To overcome the challenges, FMCG industries need to set clear goals regarding technological transformation, and goals must align with their overall business strategy. Regular evaluation of key performance indicators (KPIs) and metrics can be employed to measure progress, identify areas that require improvement and impact the technological transformation [102].

Technology transformation management is a long-term process and most FMCG decision-makers refer to I4.0 technologies as complex systems and, hence, are unwilling to maintain database systems. Therefore, "complexity to manage database system" is ranked as the sixth significant challenge in our study. However, data monitoring, cleansing, database management, backups, advanced analytics and encryptions depend highly on higher-performance databases. Therefore, a well-managed and optimized database infrastructure is essential for deriving actionable insights, enhancing supply chain operations and achieving the full potential of I4.0 technologies [103]. In such cases, stakeholders and the government must come forward to convince the top management from a financial, operational, market competitiveness, risk, productivity and organizational goal perspective.

Moreover, top FMCG industry management has an "unwillingness to adopt changes (C2)" for integrating I4.0 technologies. Government policy, high investment, technological expertise and the ripple effect of the economic crisis are the main reasons behind the unwillingness [104,105]. However, top management is the main leader of the FMCG industries and they need to deal with the prime challenges, set the objectives and strategies for adopting I4.0, encourage innovation, initiate research and development programs, change in conventional organizational ideology and initiate changemaker programs. Thus, top management can create a positive impact by making changes and adopting I4.0 to achieve supply chain resilience in the FMCG industries.

"Lack of auspicious government support and regulations (C8)" is the eighth significant challenge of I4.0 adoption in the FMCG industry. The FMCG industry does not have proper guidelines on security control capacity, cyber security and customer data vulnerability. Due to the lack of proper guidelines, the supply chain information is vulnerable and any imposter can manipulate the supply chain IT entrusted data [106]. In such cases, the government can develop proper standardization, legal, regulatory, financial and taxation programs to avoid potential vulnerabilities of I4.0 adoptions.

Finally, the government must proactively spotlight the latent benefit of profitability in digital infrastructure, which shows that "uncertain profitability in digital infrastructure (C6)" is the least significant challenge. The government can structure fiscal policy so that the SMEs can investigate a substantial investment in emerging technologies to grab competitive advantages. The challenge can be overcome easily with proper awareness-raising programs, incentives and fiscal policy.

This research covers the key elements of introducing resilience to the FMCG supply chain by implementing I4.0. The analysis determines that the requirement for substantial investment and resources, incompatible technological infrastructure and poorly structured value chains are significant challenges in this study. If the issues prevail, FMCG practitioners can transform the potential industry's supply chain and logistics into a resilient and sustainable one through smart and digitized technologies. Therefore, I4.0 adoption can promote a resilient and sustainable supply chain, which can be coined together as "Susiliency", a term that was first introduced by Hossain et al. (2023) [107] along with cybersecurity as "cyber-susiliency", where susiliency is applied to describe a supplier's overall robustness concerning sustainability and resilience. Mainly, the susiliency of the supply chain could confer multidirectional benefits to customers, not only in terms of customer responsiveness and economic, environmental and socially fair services but also in terms of business competition among the decision makers. By offering practical solutions to overcome I4.0 adoption challenges, the research becomes a valuable resource for decision-makers in the FMCG industry. This can significantly contribute to the widespread implementation of susiliency, leading to a more sustainable and responsible FMCG business landscape. Furthermore, the business competition will raise awareness among decision-makers to contribute susiliency in the product life cycle, making the process eco-friendly in FMCG business. Finally, this research identifies significant challenges in the I4.0 adoption of the FMCG sector, including high investment needs, incompatible infrastructure and fragmented value chains. These are critical roadblocks that need to be addressed for susiliency to become a reality. Therefore, by promoting susiliency in the FMCG supply chain, this study recommends implementing I4.0 by overcoming the primary hurdles, making the study a unique solution to I4.0 adoption challenges in the FMCG industry for supply chain and logistics services.

The identification of challenges through a systematic literature review, complemented by expert feedback, followed by their analysis using a multicriteria decision-making (MCDM) framework, has proven to be highly effective. This approach aligns with established practices in the field, as evidenced by similar relevant studies. For example, Alshahrani et al. (2024) [108] utilized the Delphi method to identify barriers to implementing artificial-intelligence-enabled sustainable cloud systems in the IT industry. Subsequently, they employed an integrated MCDM framework combining AHP, DEMATEL, ISM and Matriced'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) method to analyze these identified barriers. Similarly, Ahmed et al. (2024) [109] conducted a literature review and expert consultations to define AI-based imperatives for I5.0, enhancing supply chain resilience. Their analysis involved an integrated framework incorporating Pareto analysis and Bayesian BWM. Consequently, the approaches undertaken in the present study are well founded and contribute meaningfully to the advancement of research in this domain.

5. Implications

The study findings were delivered to the twelve (12) experts who participated in the Bayesian BWM survey once they were collected using the suggested framework. The experts validated the findings and provided the implications of them. Based on their suggestions, the following subsections discuss the theoretical, managerial and policy implications.

5.1. Managerial and Policy Implications

FMCG companies often operate in a complex environment characterized by high demand volatility, short product lifecycles, numerous SKUs (stock-keeping units) and intricate distribution networks [110]. These complexities are amplified by factors such as changing consumer preferences, globalization, regulatory requirements and the need to maintain a balance between supply and demand [111]. Managing this complexity is crucial for FMCG companies to ensure efficiency in the supply chain, minimize costs, optimize inventory and meet customer demands promptly. By harnessing the power of I4.0 technologies, FMCG companies can optimize their supply chains and logistics, enhance customer experiences, reduce costs, improve sustainability practices and ensure compliance with regulations [62]. Embracing these advanced technology positions can help FMCG industries to meet their challenges in the ever-evolving market landscape.

The study provides the FMCG industry community insight into applying I4.0 technologies for the smart and digitized supply chain [112]. Managers can focus on the critical challenges that need to be overcome by setting their action plans and strategies. Moreover, SMEs in the FMCG sectors of emerging economy countries can set appropriate measures to make their supply chain resilient while starting their business [113]. Thus, the study can help practitioners, policymakers, managers and consultants concentrate on supply chain resilience by applying emerging technologies.

Moreover, this research can assist managers in prioritizing tasks, particularly in sectors of the economy where resources are scarce. For instance, "requirement for substantial investment and resources (C5)" is ranked as the first challenge in the hierarchy. Therefore, with this difficulty, managers have to undergo I4.0 implementation by taking appropriate measures to overcome the challenge swiftly for better alignment, flexibility, responsiveness, communication and visibility in the supply chain and operation of the FMCG industry. Moreover, substantial investment and resources benefit stakeholders by accelerating concrete and intangible technical advancements to transform the supply chain towards resilience fully [114]. Additionally, the greater integration will enhance the FMCG sector's resilience by guaranteeing timely product monitoring and traceability, preserving correct collaborative communication with supply chain entities and developing a cutting-edge database management system. As a result, this study may help managers create effective strategies to overcome the identified obstacles and improve productivity, decision-making, operational excellence and manufacturing efficiency, which reflects the fulfillment of RO3/RQ3.

5.2. Theoretical Implications

This study has several significant theoretical implications. Existing studies often focus on individual technologies, while this study takes a comprehensive approach, examining various challenges of I4.0 adoption in the FMCG sector. This study also pinpointed the challenges that substantially influence the implementation of I4.0. Furthermore, this study promotes supply chain resilience-related challenges to adopting I4.0 to be recognized, assessed and ranked hierarchically using a Bayesian BWM framework, which fulfills the RO1/RQ1 and RO2/RQ2. Again, previous studies have lacked robust quantitative analysis. This research can aid in increasing theoretical understanding of the FMCG industry's current state and formulating strategies for adopting I4.0 to meet resilience and sustainability goals, advance widespread connectivity, and foster cooperation to improve the FMCG sector's operational effectiveness [12]. Most research overlooks the unique challenges faced by developing economies when adopting I4.0, whereas this study specifically analyses the situation in an emerging economy by providing valuable insights for similar contexts. This research illustrates how applying I4.0 may boost logistics activities, increase productivity, cut economic risk, reduce defect rates and failure and reduce FMCG's negative environmental impacts [115,116]. By combining these elements, this study presents an original and relevant investigation that has not been carried out before, addressing a critical gap in knowledge related to the FMCG sector in emerging economies. Future researchers can utilize this study as a baseline for lengthier investigations from many perspectives, providing decision experts with more relevant information on the challenges of deploying I4.0 in various additional retail industries.

5.3. Operational Resilience and Sustainability Implications

This study reveals significant implications for operational resilience and sustainability within the FMCG sector, necessitating a comprehensive strategy for navigating the complexities of I4.0 adoption. To enhance operational resilience, a substantial investment in resources underscores the importance of strategic resource allocation. Organizations must develop robust financial planning models, ensuring investments are aligned with both immediate operational needs and long-term resilience goals [115]. This mitigates financial risks and establishes a foundation for a resilient operational framework. Simultaneously, addressing the challenge of incompatible technological infrastructure requires a phased and adaptable approach to technology integration. By carefully assessing, prioritizing and seamlessly integrating I4.0 technologies with existing systems, companies can minimize disruptions, optimize operational performance and create a technologically advanced and resilient environment [117].

On the sustainability front, the identified challenges offer opportunities to align financial commitments with ecofriendly initiatives. The substantial investment requirement becomes a catalyst for prioritizing investments in sustainable technologies and processes [118]. This dual focus enhances operational efficiency and contributes to long-term environmental sustainability, positioning organizations as responsible stewards of resources. Similarly, overcoming the challenge of incompatible technological infrastructure prompts a focus on sustainable technology solutions. Selecting technologies that support operational efficiency and broader sustainability goals ensures that technological advancements contribute to a resilient and environmentally conscious operational landscape. Furthermore, addressing the poorly structured value chain emphasizes the importance of enhanced communication and collaboration within the supply chain [119].

Moreover, investments in technologies that facilitate real-time information exchange and improve overall visibility fortify the value chain's resilience and support sustainable practices. Strengthening the interconnectedness of stakeholders fosters a responsive and adaptable supply chain that is both operationally resilient and environmentally aware. Essentially, these challenges' operational resilience and sustainability implications call for a holistic and interconnected approach. By strategically managing investments, adopting adaptable technologies and fostering collaboration within the value chain, FMCG companies can successfully navigate I4.0 challenges and build a foundation that is resilient, sustainable, smart and responsive to the demands of an emerging economy.

6. Conclusions

The FMCG operations can benefit from adopting I4.0 technology in their supply chain and logistics process. As a result, I4.0 has recently acquired traction among practitioners and academics. However, the deployment of I4.0 in the growing economy's FMCG enterprise is still fragmented, presenting a research void that this study intended to fill. This study explores the pathways to compete with the challenges of I4.0 for the resilience supply chain of the FMCG industry in the emerging economy. This study can advance the FMCG industry with sustainable I4.0 adoption and management approaches. For this purpose, this study applies the Bayesian BWM method to prioritize the key challenges. In this process, a survey was conducted with the experts in the relevant field. Then, the Bayesian BWM was applied to prioritize the barriers hierarchically. This study advises that a "requirement for substantial investment and resources (C5)", "incompatible technological infrastructure (C1)" and "poorly structured value chain (C3)" are the top three critical challenges. Therefore, industrial practitioners need to focus more on these three key challenges and set their strategies to deal with them accordingly.

This study's contribution may be evaluated from a variety of angles. The theoretical significance of this research lies in combining the Bayes theorem with the BWM technique to investigate the challenges of I4.0 deployments in the FMCG business, which has never been performed before. This study goes beyond simply identifying challenges of I4.0 adoption by analyzing them through the lens of susiliency. This reframing allows for a nuanced understanding of how factors like investment needs, incompatible infrastructure and poorly structured value chains affect not just technological implementation but also broader sustainability and resilience goals. By demonstrating the multidirectional benefits of susiliency, this study expands the theoretical framework of I4.0 adoption by considering the positive impacts on customers, businesses and the environment. This broader perspective emphasizes the long-term value proposition of I4.0 beyond mere efficiency gains.

Furthermore, this strategy may be adapted and applied in industries other than the FMCG sector. This study's outcomes will help practitioners and managers change their technology adoption process into a smart and digital system to increase supply chain resilience in decision-making, efficiency and productivity by concentrating on the identified obstacles. This research also fills a gap in the existing literature by focusing specifically on I4.0 adoption in the FMCG sector within the context of susiliency. This targeted approach contributes to a deeper understanding of the challenges and opportunities unique to this industry.

This study, like other studies, possesses multiple limitations that need to be addressed in future research. This study has been conducted in the emerging economy but the results can be restricted to studying the global supply chain. Moreover, future studies can be conducted on other economic perspectives such as mixed economy, capital economy, socialist market economy and free-market economy. Furthermore, this study was conducted with industry experts in relevant fields who had academic knowledge related to the field for a long period. However, it can be possible that some biases can arise that may not reflect the original scenario. All the experts were given equal weightage in the conceptual framework while evaluating. However, a more accurate outcome can be possible by providing weights to the experts based on their relevant experience. Different theories, such as Intuitionistic theory, Fermatian theory, Spherical fuzzy theory, Pythagorean fuzzy theory and Hesitant fuzzy theory, can reduce the uncertainty of the decision process.

More significant challenges arising in the future can be studied further, as the current research has considered only nine key challenges. Finally, this type of evaluation with the Bayesian BWM can be applied in the automotive, steel, plastic, food and beverage, paint, leather, aerospace, maritime and biomedical industries. Various MCDM tools for prioritizing, evaluating and relationships can be explored in the future by applying the modified-total interpretive structural modeling (m-TISM), Partial least square structural equation modeling (PLS-SEM), DEMATEL, BWM-Z and analytic network process. Future research is recommended to investigate the adoption of I4.0 technologies in emerging countries in the long run. Moreover, the COVID-19 pandemic has influenced overall retail markets, which indicates the exploration of I4.0 technologies for resilient supply chains and logistics in the post-COVID era.

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Appendix A

Questionnaire for determining the related challenges of I4.0 adoption for FMCG supply chain resilience.

Q.1: What role do you represent in the FMCG sector?

Q.2: Mention the years of experience you have in the FMCG industry.

Q.3: Please select the key challenges for adopting I4.0 for supply chain resilience in the FMCG sector from the list compiled below. If any challenge does have a substantial impact, please choose "Yes"; otherwise, select "No". You are also invited to provide any additional challenges that you believe are necessary for implementing I4.0 in Bangladesh's FMCG industry supply chain resilience.

Table A1. Relevancy checking form of the identified challenges.

Challenges	Put "Yes" for Relevant & "No" for Irrelevant
Incompatible technological infrastructure	
Traditional organizational structure	
Uncertain profitability in digital infrastructure	
lack of highly skilled human resource	
Requirement for substantial investment and resources	
Complexity to manage database system	
Unwillingness to adopt changes	
Lack of auspicious government support and regulations	
Complexity in emerging technical equipment mobilization	
Ineffective technological transformation management	
Please provide any suggested challenges.	
1.	
2.	
3.	

Appendix B. Best to Others Challenges Matrix

Table A2. Best to Others challenges from expert feedback.

Experts	Expert Feedback	C1	C2	C3	C4	C5	C6	C7	C8	C9
Expert 1	C3. Poorly structured value chain	4	6	1	5	5	2	3	3	9
Expert 2	C5. Requirement for substantial investment and resources	8	8	4	5	1	3	4	9	2
Expert 3	C1. Incompatible technological infrastructure	1	4	2	7	5	9	5	7	4
Expert 4	C3. Poorly structured value chain	3	9	1	4	6	7	7	5	2
Expert 5	C5. Requirement for substantial investment and resources	5	3	4	7	1	4	4	7	9
Expert 6	C1. Incompatible technological infrastructure	1	4	4	5	6	6	4	9	2
Expert 7	C3. Poorly structured value chain	8	5	1	2	5	9	5	8	5
Expert 8	C1. Incompatible technological infrastructure	1	9	6	6	2	3	7	5	8
Expert 9	C5. Requirement for substantial investment and resources	8	4	7	9	1	7	5	6	8
Expert 10	C4. lack of highly skilled human resource	7	5	6	1	8	4	9	8	7
Expert 11	C7. Ineffective technological transformation management	3	4	6	4	3	9	1	5	5
Expert 12	C5. Requirement for substantial investment and resources	4	4	8	3	1	8	3	6	9

Appendix C. Best to Others Challenges Matrix

Table A3. Best to Others challenges from expert feedback.

Experts	Expert Feedback	C1	C2	C3	C4	C5	C6	C7	C8	C9
Expert 1	C9. Complexity to manage database system	8	8	9	8	2	2	6	7	1
Expert 2	C8. Lack of auspicious government support and regulations	7	7	3	6	9	6	4	1	5
Expert 3	C6. Uncertain profitability in digital infrastructure	9	2	4	3	3	1	2	7	8
Expert 4	C2. Unwillingness to adopt changes	3	1	9	3	7	7	6	6	5
Expert 5	C9. Complexity to manage database system	4	4	7	5	9	3	6	2	1
Expert 6	C8. Lack of auspicious government support and regulations	9	2	2	3	6	2	3	1	8
Expert 7	C6. Uncertain profitability in digital infrastructure	6	4	9	8	4	1	2	3	7
Expert 8	C2. Unwillingness to adopt changes	9	1	2	3	5	3	5	8	8
Expert 9	C4. lack of highly skilled human resource	7	8	7	1	9	8	7	6	7
Expert 10	C7. Ineffective technological transformation management	2	5	8	9	6	5	1	7	2
Expert 11	C6. Uncertain profitability in digital infrastructure	8	3	4	6	4	1	9	2	5
Expert 12	C9. Complexity to manage database system	6	3	6	6	9	4	6	8	1

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