Modeling of Challenges to Industry 4.0 in E-waste Management

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***Abstract*—In terms of managing e-waste, Industry 4.0 (I4.0) offers several advantages, including tracking and tracing products and monitoring sustainable practices. However, industries continue to face several implementation-related difficulties. Twenty-five articles were reviewed to find challenges. A group of five experts was assembled to confirm the challenges that had been noted. As a result, the seven most critical challenges are identified. These seven challenges are lack of infrastructure, lack of technical skills, high initial capital, resistance to change, top management, fear of losing sensitive information, and lack of collaboration among stakeholders. The cause-effect group of identified challenges was categorized and given a priority ranking using the Decision-Making Trial and Evaluation (DEMATEL) methodology. According to the results, top management commitment and a lack of infrastructure are the most pressing issues. Industries should concentrate on cause-related challenges because they have an impact on effect-related challenges. The novelty of the current study is that it could be the first study that is focused on I4.0 in e-waste management context. Therefore, the proposed study could be helpful for practitioners for the adoption of I4.0 in e-waste management context.**

Keywords—dematel, e-waste management, circular economy, I4.0; challenges

I. INTRODUCTION (*HEADING 1*)

Industry 4.0 (I4.0) is ushering in a transformative era for companies, reshaping how they conceive, enhance, and market their products. Manufacturers are integrating cutting-edge technologies like the Internet of Things (IoTs), cloud computing, analytics, artificial intelligence (AI), and machine learning into their production processes. In the realm of sophisticated factories, features such as sophisticated sensors, embedded software, and robotics take centre stage, actively collecting and analysing data to facilitate informed decision-making and achieve unprecedented precision [1], [2]. Operational data is sourced from diverse channels, including the supply chain, customer service, EPR, and other organizational elements. Intricately linked with production processes, this data generates new visibility and insight, catalysing organizational productivity. The infusion of digital technologies results in elevated levels of automation, preventative maintenance, process improvement, self-optimization, and responsiveness within the manufacturing landscape [3], [4].

Big data analysis, IoTs, and AI can offer insights on product returns, recycling rates, and e-waste production [5], [6]. By analysing patterns, volumes, and types of e-waste, these insights assist top management in allocating resources for management [1]. Tracking and tracing items throughout their lifecycle is made possible by leveraging technologies like IoT, blockchain, and computer vision [2]. This supply chain openness encourages e-waste management while discouraging practices in unofficial areas [7]–[9]. Industry 4.0 innovations can considerably improve the recycling of e-waste. Automated sorting systems that use machine vision and robotics separate metals, plastics, and valuable components from gadgets. The efficiency and capacity of recycling have increased because of automation. lessens the need for manual labor. AI algorithms help recycling processes by figuring out how to recover valuable materials with the least amount of environmental damage [10], [11]. It's crucial to remember that recycling enterprises have running expenses. By using sensors and data analytics to track the functionality and health of recycling equipment, predictive maintenance can help to reduce these expenses.

Utilizing maintenance can help discover problems with recycling equipment when it comes to managing e-waste. This makes maintenance possible and reduces downtime [12], [13]. The implementation of I4.0 in the management of e-waste has great promise, providing a number of advantages like improved efficiency, sustainability, and resource utilization. However, businesses in this industry face a number of serious difficulties. Getting upper management's commitment is a significant barrier. They might be concerned about the potential alterations that the installation of I4.0 might make to their current supply chain procedures [4], [14]. This resistance to change may hamper the move to more cutting-edge technologies. The workforce presents another difficulty. Many seasoned workers are familiar with the current equipment and procedures; therefore, they are reluctant to adopt I4.0 technologies that differ from the norm [15], [16]. It's critical to close the skills gap and make sure workers feel at ease using the newest technologies. It's crucial to recognize and take aggressive action to overcome these obstacles. Finding ways to reduce supply chain interruptions, providing thorough training and assistance to staff to ease their transition, and promoting an innovative and adaptable culture within the company are all examples of good strategies [16], [17]. Additionally, establishing effective communication channels and showcasing the long-term advantages of I4.0 can aid in winning the support of upper management. To successfully traverse these issues, management, personnel, and technology specialists must work together. In order to

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improve E-waste management and boost operational effectiveness, sustainability, and general competitiveness in a world that is becoming more digital and networked, industries must address these problems head-on.

The priority ranking and category based on the cause-effect of challenges can help the industry make decisions to improve E-waste management with the help of I4.0 [18]. Thus, the proposed study aims to fulfill two objectives. The first objective is to identify the most critical challenges in the implementation of I4.0 in the context of e-waste management. In addition, the second objective is to calculate the priority ranking and categorize identified challenges. Articles from the Scopus database are reviewed to identify the most critical challenges. The methodology used in the study is DEMTEAL which can give priority ranking and able to categorize identified challenges in the cause-effect group.

Section 2 shows the literature review, section 3 provides the methodology used in the study, section 4 gives results with discussion, and Section 5 includes the study's conclusion.

II. Literature Review

In the quest to identify challenges in implementing Industry 4.0 (I4.0) within the context of E-waste management, a thorough review was conducted using the Scopus database, examining both journal articles and conference articles. The search string employed was "challenges or barriers and I4.0 and electronic waste and management." From this comprehensive search, a curated selection of 25 articles was chosen to scrutinize the challenges associated with I4.0 implementation in the context of E-waste management. The literature review brought to light a noteworthy observation – a scarcity of studies explicitly delving into the realm of the digital supply chain, also known as Supply Chain 4.0, within the E-waste management concept. Despite a substantial volume of research, white papers, and industry reports discussing digital technologies in the context of supply chain applications, the application of I4.0 remains relatively limited. Only a minute fraction of industries actively applies I4.0 principles, and an even smaller subset explicitly focuses on adopting and implementing I4.0 within a specific industry, often through detailed case studies. This scarcity underscores the need for more targeted investigations and case studies to elucidate the nuances and challenges of implementing I4.0 in the context of E-waste management.

The focal points of attention in the discourse surrounding Industry 4.0 (I4.0) implementation revolve around the technology's facilitators and the anticipated benefits. The absence of industry-specific guidance poses a significant challenge for firms contemplating the embrace of I4.0, creating uncertainty about the prioritization of efforts—whether to focus on internal processes, customer relations, or business models [17], [19]. One of the most formidable obstacles to the adoption of I4.0 lies in the lack of enthusiasm from high-level management. Without robust support from top executives, the integration of I4.0 principles into the organizational framework becomes an uphill battle. Financial investments are paramount when contemplating digital transformation, particularly in terms of acquiring a skilled workforce and developing new organizational skills [3], [20]. Information Technology (IT) stands as a crucial component bolstering I4.0, but its operational costs are substantial. The sustainability of IT relies heavily on the return on investment derived from other digital activities, such as those associated with social media. A significant impediment to the seamless implementation of I4.0 is the resistance from employees, particularly those who are hesitant to embrace change. Older employees, in particular, may be unaware of the benefits of the latest technology and exhibit reluctance to learn about it. The transformation of such mindsets necessitates the intervention and support of top management [2], [21]. On a global scale, businesses find themselves unable to fully exploit the myriad opportunities presented by the digital transformation of supply chains. This limitation stems from a deficiency in strong leadership, practical expertise, and a clear sense of purpose and value within organizations [6], [8]. The absence of these crucial elements hinders the effective utilization of I4.0, preventing companies from harnessing the full potential of the digital revolution in the supply chain domain. The challenge lies in the technological aspects and in fostering a conducive environment for change, necessitating a comprehensive approach that encompasses leadership, skills development, and organizational alignment.

The paradigm shift ushered in by new digital technology has the potential to fundamentally reshape distribution networks. However, this transformative journey is contingent upon the availability of essential human resources. Unfortunately, the existing workforce faces a significant deficit in digital capabilities, posing a formidable obstacle to the seamless realization of these changes. The ensuing digital transition finds itself hindered and delayed due to this shortfall, emphasizing the crucial role of workforce readiness [8], [11], [13]. Organizations and individuals must cultivate essential digital skills to fully embrace digitalization, forming the bedrock for a successful transition. This includes fostering dependable business intelligence and nurturing robust digital literacy and knowledge. Organizations that meet the stringent I4.0 standards often embark on a journey of digitization, underscoring the interdependence of standards and technological evolution. The infusion of digital technologies and the cultivation of digital talent emerge as prerequisites for successfully orchestrating digital transformation initiatives. Before mapping out the trajectory of future capabilities, businesses must comprehensively evaluate their existing competencies and skill sets. This introspective analysis is vital for aligning organizational objectives with the evolving landscape of digital requirements [8], [14], [22]. For enterprises and individuals venturing into the realm of digitization, cybersecurity and privacy take center stage as critical considerations. In the interconnected tapestry of the digital landscape, where 7 billion individuals, over 13 billion devices, and the entire internet converge, the specter of cybersecurity threats looms large. The sheer magnitude of this connected world provides fertile ground for hackers to inflict significant disruptions with minimal effort, raising concerns about the potential impact on global systems. The World Economic Forum's assertion in 2014 that a threat to the internet increasingly translates to a threat to everything underscores the gravity of cybersecurity challenges in this hyper-connected era [21]–[23]. This complex interplay of technological advancements, workforce preparedness, and cybersecurity considerations underscores the multifaceted nature of the digital transformation journey. Navigating this landscape requires not only a commitment to technological innovation but also a holistic approach that addresses the human element, ensuring that individuals and organizations are equipped with the necessary skills and safeguards to thrive in the digital era.

The literature review unveils a notable scarcity of individuals actively engaged in Industry 4.0 (I4.0), despite the widespread coverage of topics like the reverse supply chain and I4.0 in numerous industry reports, academic papers, and publications. While discussions often revolve around the "enablers" of these technologies and their capabilities, a critical gap exists in the commitment from top management to earnestly support and drive the expansion of I4.0 [1], [21]. Industry standards, or the lack thereof, emerge as a significant impediment, casting uncertainty upon firms aiming to implement I4.0. The absence of clear standards leaves organizations grappling with the dilemma of where to focus their efforts—whether on internal operations, customer connections, or business models. To delve deeper into the critical challenges hindering I4.0 implementation, an expert panel comprising five members was meticulously assembled. This panel, a blend of academic and industry expertise, included two professors specializing in the digital supply chain management field and three seasoned industry professionals with extensive experience in I4.0 implementation, each boasting more than 8 years of practical insight. The primary objective was to select and validate the most pressing challenges impeding the seamless integration of I4.0 into various sectors. Through a rigorous interview process, the expert team identified seven challenges deemed most critical in the landscape of I4.0 implementation. These challenges encapsulate a spectrum of obstacles: lack of infrastructure, lack of technical skills, high initial capital requirements, resistance to change, inadequate top management commitment, concerns about the potential loss of sensitive information, and a deficit in collaboration among stakeholders. Each challenge represents a unique facet of the intricate tapestry that complicates the successful adoption and implementation of I4.0 within diverse organizational contexts. As organizations grapple with these multifaceted challenges, the insights gleaned from the expert panel provide a roadmap for targeted interventions and strategic planning. The identified challenges serve as focal points for organizations to address systematically, ensuring a more robust and sustainable integration of I4.0 principles. The convergence of academic and industry perspectives within the expert panel adds depth to understanding these challenges, paving the way for nuanced solutions that resonate with theoretical frameworks and practical realities. In essence, the journey towards effective I4.0 implementation demands a comprehensive and collaborative approach, acknowledging the interplay of technological, organizational, and human factors in shaping the future of industrial transformation.

Lack of infrastructure (C1)- To implement several facilities like high internet speed connection [2], [20], [24].

Lack of technical skills (C2)- Workers don't have adequate technical skills, which is why they cannot control the digital processes in the supply chain [4], [23].

High initial capital (C3)- To implement I4.0 in an E-waste management context, infrastructure and machines are required, which are very costly [14], [23].

Resistance to change (C4)- Workers having traditional processes and experiences don't want to be changed according to modern technologies [15], [16].

Top management commitment (C5)- Top management is not aware of the benefits of digital supply chain benefits and has a fear of return on investment [3], [17], [22].

Fear of losing sensitive information (C6)- Cybersecurity and privacy pose significant concerns for both organizations and individuals as they embrace digital transformation. Ensuring security remains a paramount concern for (Digital Supply Chain) I4.0 and its partners, and it will continue to be so [19].

Lack of collaboration among stakeholders (C7)- Stakeholders such as producers and recyclers are not sharing details about E-waste [18].

Since the identified challenges are inter-linked, DEMATEL methodology could be an effective approach to calculate priority ranking and categorise identified challenges into cause-and-effect groups.

III. Methodology

The DEMATEL is a decision-making approach that relies on comparing factors in pairs. It is employed to uncover the causal relationships among variables, showing how one factor affects another. One notable advantage of this method is that it allows experts to articulate their opinions about the impact of factors, including the direction and intensity of these effects, with greater ease.

The Process of the DEMATEL Method

Step 1: Creating the direct relationship matrix.

In order to establish the connections between the n criteria, an $n \times n$ matrix is initially created. Each row in this matrix represents the impact of an element on every element in each column. If multiple experts provide opinions, all of them must fill out this matrix. The average of all expert opinions is then calculated to produce the direct relationship matrix X. The experts used a rating scale from 0 to 4 to express their opinions about how one factor directly influences another. On this scale, '0' indicates 'no influence,' '1' represents 'minimal influence,' '2' signifies 'moderate influence,' '3' suggests 'significant influence,' and '4' denotes 'very strong influence.' Decision makers and expert groups in this study used whole numbers ranging from 0 to 4 to assess the direct impact between any two criteria.

Step 2: Calculate the normalized direct relation matrix.

Normalization involves determining the sum of all the rows and columns within the matrix. This sum is denoted as 'k,' representing the largest value among the sums of rows and columns. To normalize, each element in the direct relation matrix is divided by 'k.'

Step 3: Compute the overall relation matrix.

Once the normalized matrix is computed, the fuzzy total-relation matrix can be derived. This is achieved by generating an $n \times n$ identity matrix and subtracting it from the normalized matrix. The resulting matrix is then inverted. Multiplying the normalized matrix by this inverted matrix yields the total relation matrix.

Step 4: Final output and the creation of a causal diagram.

In this step, the sum of each row and column in matrix T (from step 3) is determined. These sums are labeled as 'D' and 'R.' Subsequently, calculations are performed to obtain 'D+R' and 'D-R' based on the values of 'D' and 'R.' 'D+R' represents the degree of importance of factor i in the entire system, while 'D-R' signifies the net effects contributed by factor i to the system. This information can be used to produce a causal diagram as the final output.

IV. Results and Discussion

The DEMATEL method was employed to identify the relationship among identified challenges to I4.0 to adopt a circular economy. With the help of steps (1), (2), and (3), direct-relation, normalized direct-relation, and total relation matrices are generated, respectively (see Tables I, II, and III). The outcome is represented in Table IV and Fig. 1. According to Table IV, challenges can be arranged in increasing order of their prominence degree (value of D+R) i.e., C3>C7>C2>C5>C1>C6>C4. Based on the value of (D+R), it is clear that high investment and lack of collaboration among stakeholders are two key prominent challenges and greatly impact the overall system.

TABLE I. Direct Relation Matrix

	C1	C2	C3	C4	C5	C6	C7
C1	0	1	3	1	1	3	3
C2	0	2	2	2	1	3	2
C3	2	2	0	3	3	1	3
C4	1	1	2	0	1	1	1
C5	3	2	2	1	0	1	3
C6	1	1	1	1	2	0	2
C7	2	2	2	1	2	1	0

TABLE II. The Normalized Direct-Relation Matrix

	C1	C2	C3	C4	C5	C6	C7
C1	0.00	0.07	0.21	0.07	0.07	0.21	0.21
C2	0.00	0.14	0.14	0.14	0.07	0.21	0.14
C3	0.14	0.14	0.00	0.21	0.21	0.07	0.21
C4	0.07	0.07	0.14	0.00	0.07	0.07	0.07
C5	0.21	0.14	0.14	0.07	0.00	0.07	0.21
C6	0.07	0.07	0.07	0.07	0.14	0.00	0.14
C7	0.14	0.14	0.14	0.07	0.14	0.07	0.00

TABLE III. The Total Relation Matrix

	C1	C2	C3	C4	C5	C6	C7	D
C1	0.36	0.50	0.63	0.43	0.48	0.56	0.71	3.71
C2	0.34	0.55	0.56	0.48	0.46	0.56	0.63	3.59
C3	0.54	0.63	0.53	0.59	0.64	0.50	0.78	4.24
C4	0.29	0.34	0.41	0.23	0.32	0.30	0.40	2.31
C5	0.56	0.58	0.60	0.44	0.41	0.47	0.73	3.82
C6	0.32	0.37	0.38	0.31	0.40	0.26	0.49	2.57
C7	0.44	0.51	0.53	0.39	0.48	0.41	0.47	3.26
R	2.89	3.51	3.67	2.89	3.21	3.08	4.24	

Based on (D-R) values, identified challenges can be categorized into cause-and-effect. Cause challenges have higher influencing power than effect challenges. In other words, effect challenges are impacted by cause challenges. Thus, challenges should be solved as a priority.

Since C1, C2, C3, and C5 have positive values of (D-R) these challenges are categorized as cause challenges. The remaining challenges C4, C6, and C7 are effect challenges as they have negative values of (D-R). The challenges caused by a lack of infrastructure, technical skills, high initial capital, and top management commitment should be a priority while eliminating challenges. Top management could take help from already developed industries to adopt I4.0 for better E-waste management [25]. The government can provide joint tax subsidies to industries for their contribution towards sustainability. This fund can be used to buy infrastructure and technical skilled workers. Industries can conduct training sessions for their workers. As the challenges, namely lack of infrastructure and top management commitment, have a higher value (D-R), these challenges can be considered the most crucial challenges to I4.0 in the E-waste management context.

TABLE IV. The Final Output

	D	R	D+R	D-R	Group
C1	3.71153	2.89086	6.60239	0.82067	Cause
C2	3.59827	3.51239	7.11067	0.08588	Cause
C3	4.24187	3.67800	7.91987	0.56387	Cause
C4	2.31765	2.89275	5.21040	-0.57510	Effect
C5	3.82036	3.21423	7.03459	0.60613	Cause
C6	2.57353	3.08863	5.66215	-0.51510	Effect
C7	3.25966	4.24600	7.50566	-0.98634	Effect

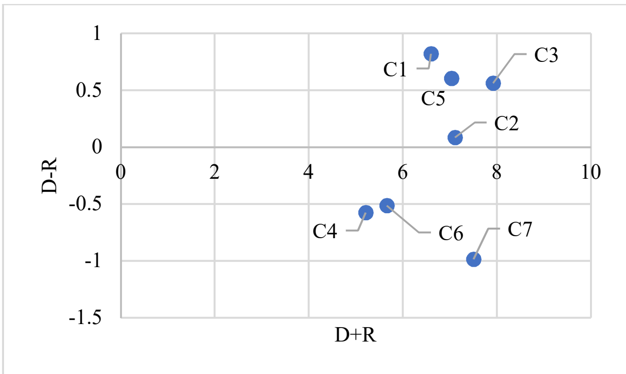

Fig. 1. Cause-effect diagram

According to values of (D-R) and (D+R), a DEMATEL digraph is produced (See Figure 1). (D-R) and (D+R) values are taken as Y-axis and X-axis, respectively. Challenges above the horizontal line are considered cause challenges, and challenges below the horizontal line are effect challenges.

This study adds to our understanding of I4.0 challenges in the context of EWM in both theoretical and practical ways. By highlighting important obstacles and classifying them as cause-and-effect obstacles, the study adds to the body of knowledge already available on the topic. The DEMATEL digraph is one practical application that gives industries a tool to prioritize and decide how to respond to these challenges.

V. Conclusions and Implications

Digital technology's potential to revolutionize distribution networks depends on how problems like the lack of qualified labor are resolved. The inability of the present workforce to possess fundamental digital skills prevents the smooth implementation of digitalization. Achieving I4.0 standards requires businesses and individuals to prioritize digital skills, such as business intelligence and literacy. Concerns about privacy and cybersecurity become more important in an increasingly interconnected world. The literature emphasizes how important challenges are to be addressed, and top management supports this. The seven major challenges identified by an expert panel are the lack of infrastructure, technical skills, high initial capital, resistance to change, top management commitment, fear of losing sensitive information, and lack of collaboration. The successful integration of Industry 4.0 in diverse sectors necessitates identifying and resolving these challenges. DEMATEL methodology was used to give priority ranking and categorize identified challenges in the cause-effect group. Based on results, top management commitment and lack of infrastructure are the most critical challenges. Industries should focus on challenges that fall under the cause category as they impact effect challenges.

This study contributes theoretically and practically to understanding I4.0 challenges in the EWM context. The research identifies and categorizes key challenges as cause-and-effect challenges, enriching the existing literature on this subject. One practical implication is the application of the DEMATEL digraph, offering industries a tool to prioritize and make informed decisions regarding these challenges. However, certain limitations should be acknowledged. The study exclusively utilized the Scopus database, potentially resulting in limited articles due to specific search strings.

Additionally, the study is generalized and may exhibit variations across different sectors, prompting the need for sector-specific investigations. Future research avenues could explore sectors in-depth, allowing for a more nuanced understanding of I4.0 challenges. Furthermore, an extension of this study could focus on examining the enablers of I4.0 in the E-waste context. Another promising area for future research lies in investigating challenges within reverse logistics in E-waste management, providing a comprehensive exploration of this critical domain.

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