An intelligent model to identify industry 4.0, IoT and circular economy adoption barriers

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Abstract

In the industry 4.0 idea, new cutting-edge techniques like the Internet of Things (IoT) are advocated. There is still a long way to go before IoT is widely adopted in the circular economy. The goal of this research is to identify the most significant impediments to the integration of IoT in the circular economy in the manufacturing industry. For this purpose, survey research was carried out to provide a framework for the assessment of the hurdles to IoT adoption in the circular economy. This led to a new approach that combines the SWARA and TOPSIS methodologies based on MCDM. The SWARA model is employed to compute the weights of criteria, while the TOPSIS approach is used to rank different manufacturing businesses under the identified obstacles.

Keywords: MCDM; Industry 4.0; IoT; TOPSIS; SWARA

1. Introduction

Global Circular Economy (CE) is an economic model that is "restorative and regenerative by design" that takes into consideration environmental repercussions, scarcity of natural resources as well as economic benefits[1]. [2]Practically speaking, CE concerns, such as minimizing waste creation and GHG emissions, need substantial innovation in product design, business structures, resources, and supply chain. CE techniques are primarily focused on ensuring that the economic value of elements, resources, and products is maintained for the longest possible length of time while also ensuring that environmental consequences are minimized throughout the period [3]When it comes to creating a profit from "the flow of goods and materials over time," CE challenges various firms to find the best methods to continually reuse products and resources [4]. Many businesses and organizations throughout the globe are now discussing if and how CE should be included in their long-term plans. The key driver behind this trend is governmental agencies and population in general pressure, or even the ambitions of enterprises and organizations, which demands all stakeholders to build an environment for a tomorrow with the maximum level of resilience.. of sustainability. To improve both the company's financial and environmental standing, CE has developed a systematic approach to increasing resource efficiency [5].

There is a slew of new reviews in the research examining the role that information devices (DTs) play in advancing CE. Studies have looked at the assignment that is involved in data grouping, integration, and analysis, as well as the Industry 4 technology of cyber-physical constructions, Broadcast identification (RFID) [6] and IoT [7]–[9], cloud production [10], and manufacturing techniques [11]. According to their findings, DTs in CE may benefit from a variety of different types of settings, such as lifecycle and digital management, supply chain management, recycling and reuse technology, circular business structures, and resource efficiency, to name just a few [11]. In product-service architectures, there are several topics of research, such as how to utilize, repair, reuse, recover, and things in this world goods in an articulate way [12].

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The academic world, consumers, regulators, and others have lately begun to pay more attention to CE; yet, the collection of knowledge on this topic is in its early stages[13] and even the literature lacks a clear definition of CE [14].

Until now, the Ellen MacArthur Institute has offered the most frequently recognized definition of CE as a "system rehabilitative and regenerating by design, which attempts to preserve goods, elements, and resources at their greatest usability and value" Industrial ecology, blue economy, biomimicry, and Cradle-to-Cradle are just a few of the additional fields of research that support the notion of CE [15]. According to CE, producers often employ raw resources to make things that they subsequently sell to consumers and discard as trash, which is in opposition to the planned economy[16]. Several closed-loop cycles of reuse, remanufacturing, and recycling items are provided by CE to facilitate economic growth without causing harm to the environment or depleting natural resources.

Modern technologies like the Internet of Things (IoT) have made it easier to apply CE's theoretical basis to real-world economic activities. Digitalization and the Internet of Things (IoT) have had a significant influence on CE design and implementation in recent years, according to various research. The Ellen MacArthur Foundation, which has done a lot to promote CE, has released two studies on this subject.

IoT is expected to contribute $14 trillion by 2020, with approximately 34 billion devices installed in diverse aspects, such as city infrastructures and smart grids and residential and home automation systems, mass transit, industrial systems, universal health care, and military applications, according to the authors. Users may engage in information networks more actively with the aid of IoT, which gives specific sensors to gadgets [17]. Smart and linked stand-alone items are made possible by the Internet of Things (IoT), which also aids in material monitoring and the collection and management of trash. Reuse, remanufacturing, and recycling are all made possible as a consequence. It would be possible to collect an enormous amount of data in only a few minutes with this current approach. In addition, the Internet of Things (IoT) enables businesses to track and monitor the actions of their goods, which enables them to give better technical assistance. Renovation and end-of-life activities might benefit from IoT Monitoring the condition of items is critical for every business. The Internet of Things (IoT) is a useful technology because it can give the firms a real-time monitoring system of their products' use, status, and location throughout the product's lifetime [18]. When manufacturing managers can learn how customers use and execute their goods, they acquire a better understanding of how they can better connect with individuals. As a consequence, manufacturers and their consumers will be able to engage in meaningful dialogue.

When IoT is integrated with other sectors, such as CE, it has the potential to provide a great deal of new value and innovations. Resource efficiency is achieved through extending the usable life of scarce funds, increasing the efficiency of assets, and regenerating natural capital for future use. It has also been established in research that the Internet of Things (IoT) is an excellent tool for the implementation of circular schemes and business models in companies and organizations. IoT may facilitate the expanded use of items in a circular fashion since it can allow for the monitoring of a product's current condition, use, and location by several users simultaneously. New opportunities for the economic cycle are opened up by IoT, which serves as a service enabler by organizing current information about asset statuses, locations, performance, and quality across time in a way that is easy to use. Many CE inventors have found practical solutions to resource-related issues using this technology. The CE models' feedback-rich character may be beneficial for extracting value from large amounts of data generated by IoT.

As a generalization, IoT includes numerous technologies developed to link, monitor, and operate items including household appliances, sensors, industrial equipment, and automobiles through a network of data. Internet-enabled physical items such as smart machines, actuators, labels, and monitors may establish a network and communicate with each other to acquire higher value by sharing data and creating new insights. Identity, connectivity, and interactivity are the three pillars of the Internet of Things (IoT).

For example, in situations where items can perceive their surroundings and interact with one other, they aid in understanding the complexity and responding to it correctly. One of the most important variables that may significantly enhance CE is IoT. . The present take-make-dispose economy is made more efficient by any advancement of DTs, but it is still unable to properly solve the most pressing threats to natural resources. The relationship between DTs and the economy gives an

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excellent foundation for rethinking the underlying structures and encouraging CE, on the other hand. With the help of IoT and cloud technology, the CE basic principles may be applied to new business models more effectively

There are presently no comprehensive studies on IoT-related CE problems, however, numerous efforts are being conducted in this area. In addition, more research is needed to thoroughly map the CE approaches to the novel DTs. IoT for CE is yet to be fully implemented in the actual world, according to the literature. As a result, further research is needed to examine the barriers to the widespread adoption of IoT-enabled circular solutions.

Thus, this article is aimed at finding and analyzing the main obstacles to the deployment of IoT in the CE environment. To add to this, the study's goal is to give case studies on the IoT and propose prospective avenues for further research into this revolutionary field. As a result, IoT is seen as a well-organized instrument that may handle CE concerns.

Its SWARA-TOPSIS integrated strategy is being used to analyze IoT adaptation barriers. For this goal, 22 criteria have been established. SWARA (stepwise weight assessment ratio analysis) approach was used to establish the weights of these criteria. It was based on professional judgments and assessments that collected the data. As a result of the weights assigned, SWARA-TOPSIS was utilized to pick potential alternatives using the TOPSIS (technology for order preference by the resemblance to a deal solution) approach.

The rest of the paper is organized as follows: complete literature analysis is presented in Section 2. The proposed model is discussed in detail in Section 3, along with a novel methodology that is suggested. Results are presented in Section 4. Discussions and conclusions are all included in Section 5.

2. Related Work

Because of the increasing population, the advancement of the economy, and people's increased quality of living, energy resources are being ever more utilized. There is a growing need for these resources, thus according to Preston & Herron [19]. This has led to a wide range of operating difficulties for businesses. Resources are scarce, which increases the cost of inputs, resulting in goods that are no longer competitive on the market Conventional linear economy models continue to be used by the vast majority of manufacturing firms [20]. Many valuable resources are wasted by conventional techniques of recycling and reusing materials that are not cost-effective.
Policymakers throughout the world have put enormous pressure on supply chains to take sustainability into account in all of their operations [21]. To avoid the unimaginative disposal of end-of-life items, manufacturing businesses are being forced to completely convert from straight to circular methods due to new social and environmental concerns.
Information technology (IT) experts have been tasked with helping their respective companies make the transition to CE by incorporating new technologies into their strategies. A well-structured framework with the essential IT skills is still lacking, though [22]. Integration of the Internet of Things (IoT) with IT is a challenge in both academic and practical today. Current networking and security systems have been modified to effectively handle the enormous population of IoT devices. In addition, the huge amount of data generated by IoT systems necessitates the integration of cloud computing with IoT solutions. By 2030, Europe alone may reap the benefits of €1.8 trillion from this approach alone. CE must be implemented by companies to take advantage of these possibilities; for example, supply chains must transition from linear to illogical reasoning, and product-oriented strategies must be replaced with provider ones [23]. Minimize, Reuse, and Recycle are the three Rs of CE. The 3Rs may improve the sustainability of the firms' activities [24]. Users benefit from CE's ability to assist them in better use and repurpose the resources they have at their disposal. Consumers may be persuaded to choose one firm over another by an all-inclusive perspective of the business activities of that company, as well as by the business model that it offers[25].

The CE's insightful comments and encouragement of the value-creating procedures suggest a delivery system that carries out the value proposition properly while increasing circularity and through constriction, slowed and closed resource flows [4], and get some real worth mechanisms that enable the firm to take part in the value only just generated as profit [26]while trying to follow the CE values[4]. Companies must thus understand how the business model may promote circularity

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as well as strategies for generating and capturing value [27] to achieve CE. Several recent research has examined the role of DTs in empowering CE. To be successful in CE, it is necessary to consider both the forward and backward flows of goods, materials, and components. Reverse Logistics (RLs) and closed supply chains may help with this. Many RLs actions have to be prioritised in a specific way: reuse is often favoured over recycling since most of the inherent value of the product remains intact throughout the reuse process.

Products also need to be redesigned to improve the processes of reuse, refurbishing, reprocessing, and recycling. As a result, eco-design, customization, product life extension, standardization, reprocessing, and material selection might all be part of a design-for-x approach to product development.

There are three levels of CE system implementation: micro and macro[28]. A single firm is singled out in the first study for making the transition to CE.

After then, eco-industrial parks are created by collaborating with other sectors of the economy, a process known as industrial symbiosis.

Finally, the final step takes a broader look at the efforts undertaken by cities, regions, or countries to encourage the adoption of the CE paradigm. Keep in mind that a bottom-up or a top-down strategy might be used to deploy CE. To begin, the shift to CE is necessitated by the idea of gathering economic output from a single source. A "command and control" approach is largely responsible for this change in policy in the second example. Only considered as a key (e.g., product firmware) can be advanced to deal with intelligent devices, which may increase the product's capacity to be upgraded[29].

A closed-loop economy is often not compatible with CE. Recycling and smart solutions are the main focus of this effort. Since the goal is to preserve goods, resources, and elements at their highest value, it can be claimed that CE is an ongoing improvement cycle that distinguishes between biochemical and molecular cycles. By adopting a CE corporate structure, Europe's industrial industry would save an estimated 570 billion euros annually on material costs, with a potential opportunity for growth of 320 billion euros by 2025. As a result of resource constraints, CE helps to build wealth and increase the employment rate. To move beyond a linear "take, manufacture, discard" approach to CE, technological solutions need to be reimagined. DTs and related business models for the CE development in firms have only been the subject of theoretical study in the literature up to this point, with no empirical proof provided. There is a lack of information on how DTs may aid firms in the creation of CE.

Prospective CE solutions might be difficult to implement because of the gap between recognizing a viable solution and applying it to a company's primary operation. As a consequence, it's critical to know how businesses use DTs to innovate their business models to facilitate CE. In the context of the Industry 4.0 concept, digital technology advancements have the potential to enable CE. Products may be identified and tracked across a supply chain using these techniques, which reduces the need for product ownership in product-service systems and increases industry efficiency. Current knowledge has been reinforced and critical research gaps identified by review studies undertaken in this field. The assessment research was performed in this domain. As a result of its conceptual character, the existing literature lacks sufficient evidence to support its claims. There are just a few case studies out there, and they tend to focus on a specific film or industry, which reduces the probability of capturing the larger implications of the study. DTs' influence on CE's business model innovation has been identified as a need by the evaluations.

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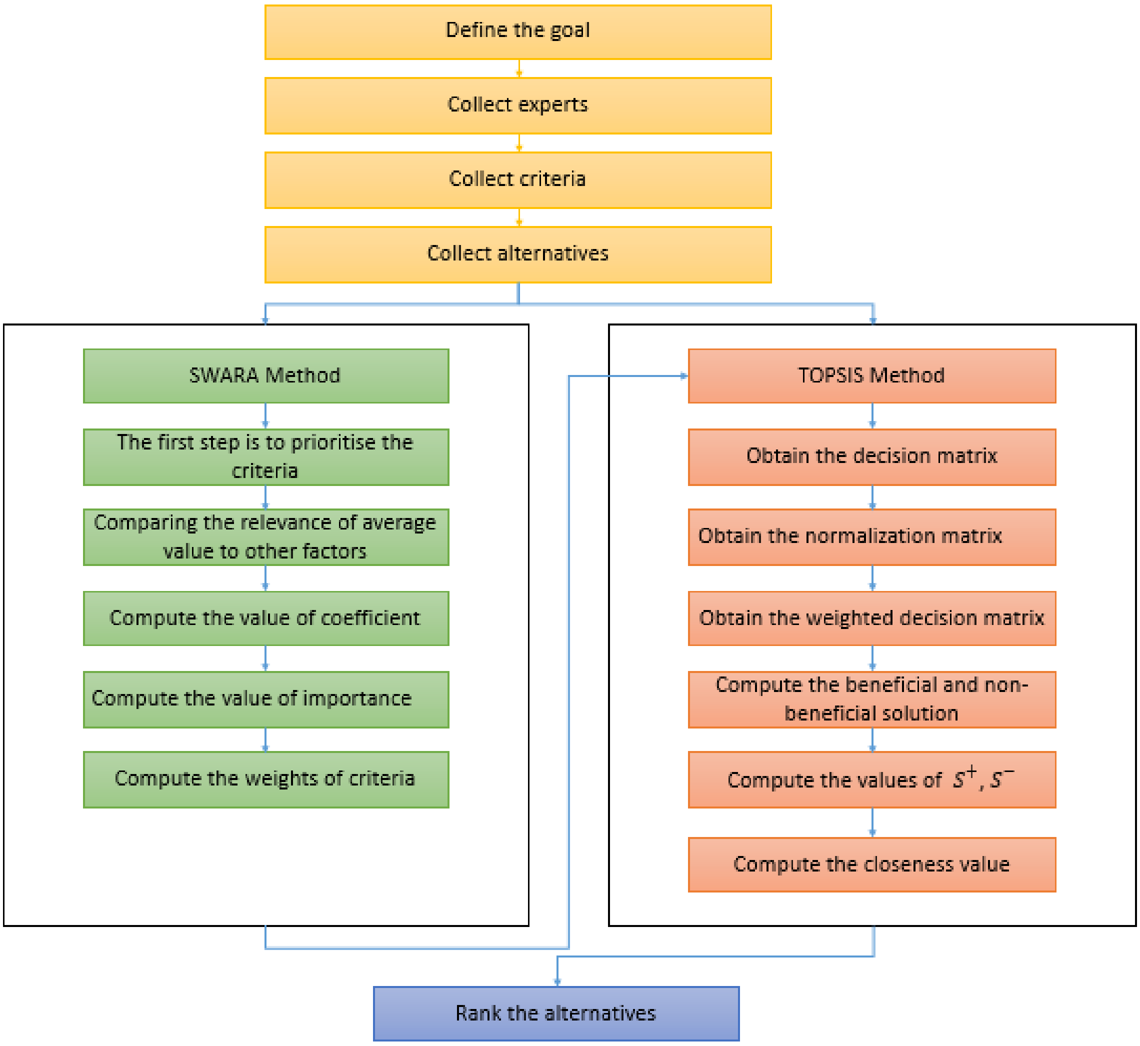

Figure 1: The framework of the study.

3. The Proposed Model

IoT barriers assessment was conducted using a 5-step process in this research. The first step was to undertake a comprehensive study of the existing literature. Researchers picked papers that dealt with IoT barriers extensively, and a huge number of criteria were compiled. IoT barriers were derived from research. 4 alternatives were contacted in the second phase. To narrow down the list of criteria, the possibilities were analyzed one by one, with consideration given to both. The SWARA approach was used to calculate the weight of each criterion in the final stage. Experts were tasked with evaluating choices in the fourth phase. The alternative was given points by experts who rated the significance of each of the criteria. The final phase was to include weights from SWARA and TOPSIS methods, and the best alternative was chosen. The procedure outlined in this investigation is shown in Figure 1.

Weight evaluation ratio step-by-step analysis
Kerulien et al. presented SWARA to the literature as one of the multi-criteria decision-making strategies [30]. Using the experts' knowledge and expertise, the approach is founded on the basic logic of establishing weights[31]. The following are the stages in the SWARA procedure:

Step 1: The first step is to prioritize the criteria.

The most significant factor is rated "1" and the least important criteria is ranked "n" based on the judgments of experts.

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Step 2: Comparing the relevance of average value to other factors (s_j)

The s_j value, which is the average value's relative significance, is determined in this stage [30]. Experts are asked to rate each criterion based on how important it is in comparison to the following criterion in the rating. An evaluation of each criterion is made against the next one in the ranking process.

Step 3: Compute the value of the coefficient k_j

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (1)$$

Step 4: Compute the value of importance

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{x_{j-1}}{k_j} & j > 1 \end{cases} \quad (2)$$

Step 5: Compute the weights of the criteria

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_j} \quad (3)$$

Another MCDM approach is TOPSIS,[32]. This method yields the positive ideal from the criteria's greatest possible values, while the criteria's worst possible values provide the negative ideal solution[33]. According to [34], the TOPSIS process is broken down into six phases.

Step 1: Obtain the decision matrix

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (4)$$

Step 2: Obtain the normalization matrix

$$N = \begin{bmatrix} n_{11} & \cdots & n_{1n} \\ \vdots & \ddots & \vdots \\ n_{m1} & \cdots & n_{mn} \end{bmatrix} \quad (5)$$

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (6)$$

Step 3: Obtain the weighted decision matrix

$$D_{ij} = N_{ij} * W_j \quad (7)$$

Step 4: Compute the beneficial and non-beneficial solution

$$B^+ = \{d_1^+, d_2^+, d_3^+, \dots \dots \dots d_n^+\} \quad (8)$$

$$B^- = \{d_1^-, d_2^-, d_3^-, \dots \dots \dots d_n^-\} \quad (9)$$

Step 5: Compute the values of S^+, S^-

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$$S_i^{+} = \left[\sum_{j=1}^{n}(d_{ij} - d_j^{+})^2\right]^{\frac{1}{2}} \qquad (10)$$

$$S_i^{-} = \left[\sum_{j=1}^{n}\left(d_{ij} - d_j^{-}\right)^2\right]^{\frac{1}{2}} \qquad (11)$$

Step 6: Compute the closeness value and rank alternatives

$$C_i = \frac{S_i^{-}}{S_i^{-} + S_i^{+}} \qquad (12)$$

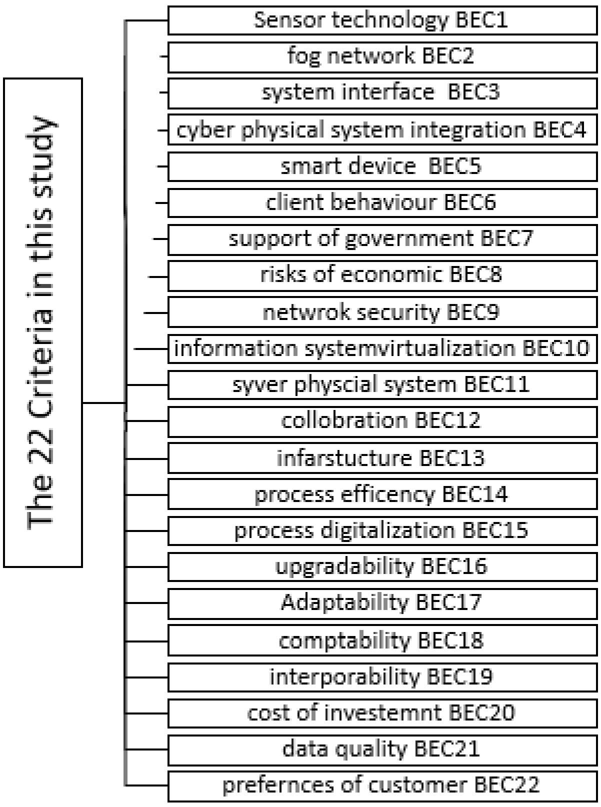

Figure 2: The 22 criteria.

4. Results

Literature research and interviews with DEs were used in this study to examine the industrial industry to determine the major obstacles to IoT adoption for the circular economy. For the first phase, a thorough study of multiple online databases, such as Scopus, Sage Publications, Web of Science, Emerald, and the IEEE Explore, was conducted to identify the most significant hurdles in the literature. The 22 criteria are shown in figure 2.

Identifying the major hurdles to IoT adoption for the CE in the industrial industry will be the first step for a set of decision specialists (DEs) from several disciplines, such as IT, environmental sustainability, computing, and the circular economy. It's no secret that these professionals are

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involved in promoting IoT and the circular economy. DE and LV criterion ratings are shown in Tables 1 and 2,3 and then aggregate as shown in table 4.

Table 1: First expert values

	BEA1	BEA2	BEA3	BEA4
BEC1	9	7	1	1
BEC2	3	7	1	9
BEC3	1	1	1	7
BEC4	1	7	1	7
BEC5	9	9	7	9
BEC6	7	7	1	1
BEC7	7	7	9	3
BEC8	1	9	1	3
BEC9	3	1	1	7
BEC10	3	1	9	9
BEC11	1	9	1	7
BEC12	7	1	9	3
BEC13	3	3	7	9
BEC14	9	7	7	1
BEC15	3	1	1	7
BEC16	7	7	1	1
BEC17	7	1	9	7
BEC18	3	3	9	1
BEC19	7	1	1	7
BEC20	7	7	1	9
BEC21	9	7	3	3
BEC22	7	3	1	3

Table 2. Second expert value

	BEA1	BEA2	BEA3	BEA4
BEC1	9	9	9	1
BEC2	1	9	7	1
BEC3	9	3	9	9
BEC4	1	1	9	3
BEC5	1	1	7	7
BEC6	3	3	9	9
BEC7	9	3	1	7
BEC8	7	1	9	9
BEC9	7	1	3	7
BEC10	1	7	9	3
BEC11	7	3	3	3
BEC12	9	3	7	9
BEC13	7	3	7	3
BEC14	3	1	1	1
BEC15	9	1	9	7
BEC16	1	7	9	1
BEC17	1	3	1	1
BEC18	7	9	7	9
BEC19	9	1	7	3
BEC20	7	1	9	1
BEC21	1	3	7	1
BEC22	1	7	1	7

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Table 3.:Third expert value

	BEA1	BEA2	BEA3	BEA4
BEC1	1	7	9	9
BEC2	7	1	7	9
BEC3	1	1	9	1
BEC4	3	9	3	7
BEC5	1	7	3	1
BEC6	7	9	1	9
BEC7	1	3	1	1
BEC8	7	1	1	9
BEC9	1	3	7	9
BEC10	1	7	7	9
BEC11	7	3	3	1
BEC12	7	3	3	9
BEC13	1	9	9	7
BEC14	9	7	1	3
BEC15	9	7	1	1
BEC16	1	9	7	1
BEC17	7	7	1	9
BEC18	1	1	1	1
BEC19	1	7	9	7
BEC20	1	7	9	1
BEC21	9	1	9	7
BEC22	9	1	3	3

Table 4: The aggregate three experts.

	BEA1	BEA2	BEA3	BEA4
BEC1	6.333333	7.666667	6.333333	3.666667
BEC2	3.666667	5.666667	5	6.333333
BEC3	3.666667	1.666667	6.333333	5.666667
BEC4	1.666667	5.666667	4.333333	5.666667
BEC5	3.666667	5.666667	5.666667	5.666667
BEC6	5.666667	6.333333	3.666667	6.333333
BEC7	5.666667	4.333333	3.666667	3.666667
BEC8	5	3.666667	3.666667	7
BEC9	3.666667	1.666667	3.666667	7.666667
BEC10	1.666667	5	8.333333	7
BEC11	5	5	2.333333	3.666667
BEC12	7.666667	2.333333	6.333333	7
BEC13	3.666667	5	7.666667	6.333333
BEC14	7	5	3	1.666667
BEC15	7	3	3.666667	5
BEC16	3	7.666667	5.666667	1
BEC17	5	3.666667	3.666667	5.666667
BEC18	3.666667	4.333333	5.666667	3.666667
BEC19	5.666667	3	5.666667	5.666667
BEC20	5	5	6.333333	3.666667
BEC21	6.333333	3.666667	6.333333	3.666667
BEC22	5.666667	3.666667	1.666667	4.333333

Step 2: compute the comparative weight

Step 3: compute the value of the coefficient

Step 4: compute the value of importance

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Using SWARA, the DEs play an important role in analyzing and computing the weights for each barrier, as shown in figure 3. The significance of each obstacle was assigned to each DE. The experts arranged all of the accessible qualities in ascending order.

According to SWARA, the most critical barrier was ranked first, while the least significant barrier was ranked last

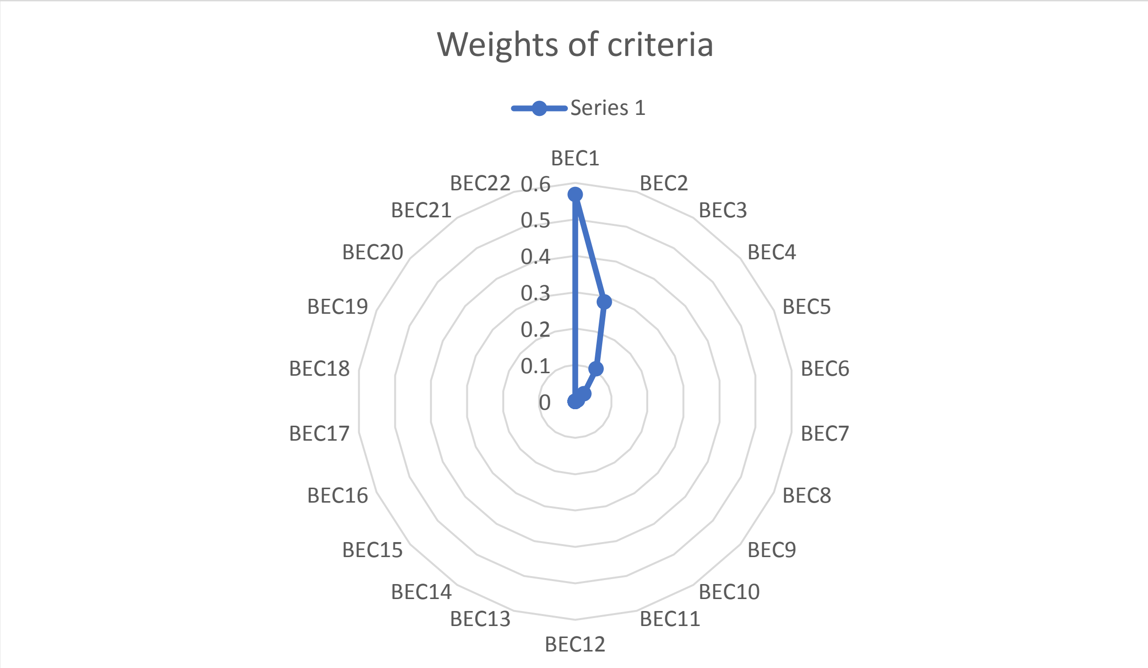

Figure 3: The weights of criteria.

Normalize the decision matrix by the TOPSIS method as shown in table 5. Then compute the weighted normalized decision matrix. Then compute the beneficial and non-beneficial values. Then compute the value of S^+, S^-. Then the closeness value is computed. The rank of alternatives depends on the largest value of closeness value. Figure 4. Show the rank of alternatives. From figure 4 the BEA2 is the best alternative and BEA4 is the worst alternative.

Table 5: The normalization decision matrix.

	BEA1	BEA2	BEA3	BEA4
BEC1	0.512952	0.348548	0.389885	0.179954
BEC2	0.620942	0.538666	0.17722	0.611843
BEC3	0.512952	0.475293	0.673437	0.46788
BEC4	0.296972	0.602038	0.602549	0.611843
BEC5	0.512952	0.348548	0.389885	0.179954
BEC6	0.620942	0.538666	0.17722	0.611843
BEC7	0.512952	0.475293	0.673437	0.46788
BEC8	0.296972	0.602038	0.602549	0.611843
BEC9	0.512952	0.348548	0.389885	0.179954
BEC10	0.620942	0.538666	0.17722	0.611843
BEC11	0.512952	0.475293	0.673437	0.46788
BEC12	0.296972	0.602038	0.602549	0.611843
BEC13	0.512952	0.348548	0.389885	0.179954
BEC14	0.620942	0.538666	0.17722	0.611843
BEC15	0.512952	0.475293	0.673437	0.46788
BEC16	0.296972	0.602038	0.602549	0.611843
BEC17	0.512952	0.348548	0.389885	0.179954

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BEC18	0.620942	0.538666	0.17722	0.611843
BEC19	0.512952	0.475293	0.673437	0.46788
BEC20	0.296972	0.602038	0.602549	0.611843
BEC21	0.512952	0.348548	0.389885	0.179954
BEC22	0.620942	0.538666	0.17722	0.611843

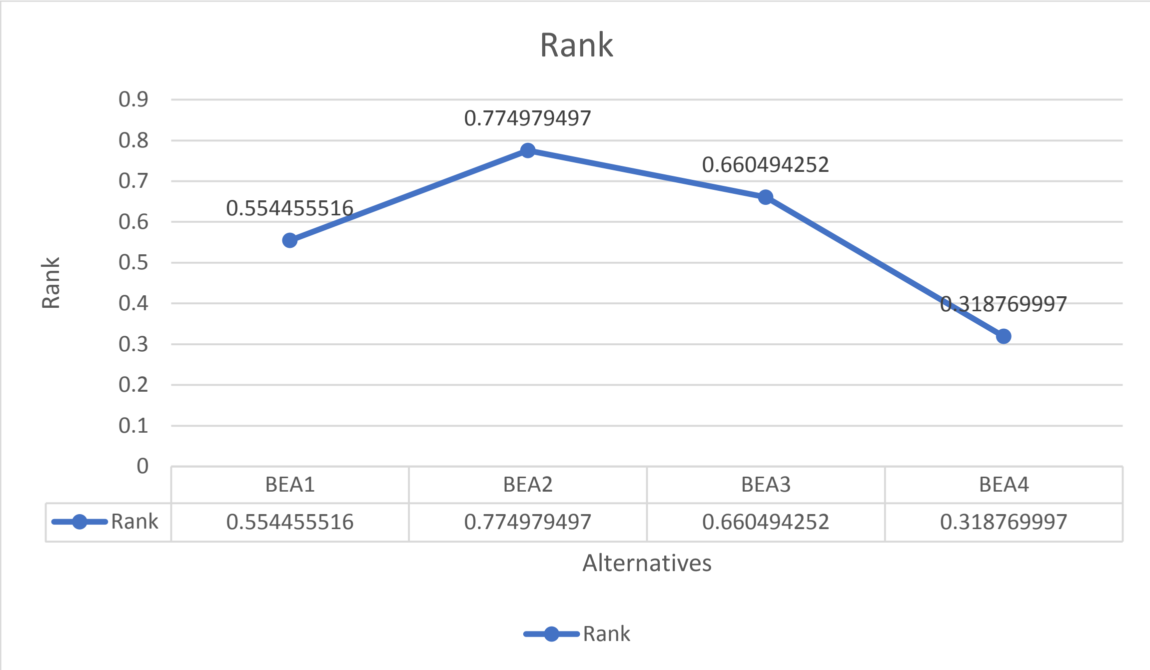

Figure 4: The rank of alternatives.

5. Conclusion

IoT adoption in the industrial sector has been hindered by several factors that have been analyzed using a unique MCDM technique. By conducting interviews with DEs and reviewing the literature, this research came to this conclusion. 22 major roadblocks were identified as a result of the survey, including standardizing infrastructure, virtualizing the automation system, improving the quality of data, adaptability, catering to customers ’ preferences, utilizing sensor systems, developing smart devices, upgrading, ensuring seamless integration, reducing financial risk, increasing investment cost and other.

It was shown that a new MCDM technique was effective in identifying, classifying, and evaluating IoT adoption hurdles. To assess the research framework, a SWARA and TOPSIS approach was developed. The DEs play an important part in analyzing and computing the weights for each barrier when utilizing SWARA to calculate the weights. As a result, each DE was required to rate the relevance of the various barriers to IoT deployment in CE concerning the overall aim. The TOPSIS method is used to compute the weights of the criteria.

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