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Barriers to the adoption of digital technologies in a functional circular economy network

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Abstract

Technologies are developing at a fast rate in which every new technology has an ample range of applications. Digitalization has taken rapid strides over the last few years which plays an important role in Industry 4.0. The digital revolution is fundamentally changing the way people live and work, and the public is optimistic about the opportunities Industry 4.0 can offer for sustainability. All organizations or industries have not been equipped with the latest technologies to adopt digitalization. This is mainly due to the lack of knowledge and expertise and unclear benefits of the technology. The study identifies the potential barriers in the adoption of digital technologies through two processes namely Total Interpretive Structural Modelling (TISM) and Matrix Multiplication Applied to Classification (MICMAC) analysis. Using these models, the study interprets the barriers and analyses the relationship between the barriers. The barriers need to be treated on a priority basis and must be eliminated to successfully adopt digital technologies. From the developed TISM model and MICMAC analysis, the most influential barrier for the adoption of digital technologies in Industry 4.0 are negative perception towards technology because, this barrier will not depend on other barriers and hence managers must give a topmost priority to avoid the disruption in the system for the adoption of digital technologies. The study talks about other key barriers which influence the implementation of Industry 4.0, some of them being unclear benefits and lack of awareness. These barriers act as the primary variables which disturb the system and hinder the approach while additional barriers pose as secondary variables in the system. This research aims to help Industry 4.0 stakeholders – public and private sector leaders, industrialists– to get a lot more clarity on the opportunities that the digital revolution can offer for sustainability and to ensure that Industry 4.0 delivers sustainable functions.

Keywords Digitalization · Supply Chain · Barriers · Total interpretive structural modelling · MICMAC · Industry 4.0 · Circular economy

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1 Introduction

Many developing countries have industrial policies that focus on the industrialization of natural resources and due to rapid growth in population and demand for natural resources, there exists a scarcity of resources involving multifaceted operational challenges (Agrawal et al., 2021). The output products have been very expensive due to exploitation and scarcity of natural resources giving rise to the need for conservation of materials (Kumar et al. 2021a, b). Moreover, material utilization would increase five times more by 2050, leading to higher utilization of natural resources (Nishitani et al. 2022). To solve this issue, there exists a need to develop sustainable industrialization. According to the Brundtland commission report "*The development which satisfies the needs of the present without compromising to meet the requirements of future generations*" is defined as sustainable development. Governments need to create a framework for universal access to technological information to bolster development in technology for expanding sustainable development.

Digitalization is one of the key factors which brings more light to Circular Economy (CE) concept. Digitalization involving artificial intelligence plays a significant role in the development and growth of CE. With digitalization, the knowledge and the location of the product is known. One of the important points to understand in CE based business is that the products are shared whenever possible rather than selling the products. Digitalization acts as a key enabler in this process and the focus is shifted towards Product Service Systems (PSS) and the transformation towards CE is accelerated. Usually there is a huge chunk of data in CE interrelated systems. Digitalization gives a new dimension to handle the huge data thereby improving the process of decision making. It also gives an idea about the waste estimation of a product and how the waste could be reused (Fernano et al., 2022). Digitalization also talks about the logistical scheduling of the product. The distribution channels become virtualized with digitalization. The customers could get the information about the product through online channels and products can be sold digitally which reduces environmental impact and CE business models.

CE's important enabler is digitalization. To facilitate circular systems, the introduction of digital technologies plays an important role but there is limited amount of information regarding the importance of digitalization towards the transition of circular economy. Resources are used more effectively after the implementation of digitalization. To make the move towards CE and to enhance product life cycle, access to data such as product resource consumption is possible via digitalization. In PSS business models, emerging technologies such as RFID plays a critical role in gathering information regarding how the product has been functioning. For instance, the data from the RFID could be used to understand the quality of products used which helps in the overall product development.

The COVID-19 pandemic has created an opportunity for countries to build back-up plans that would change the current situation, production and consumption to progress for a better sustainable future. Sustainable production is about maximizing effective resources and decoupling financial stability from environmental degeneration (Mathivathanan et al. 2021). A greener future and poverty alleviation would be possible through the help of sustainable production. For example, in the production of ammonia, a technology called Process Intensification (PI) technology. PI technology helps in reducing cost and optimizing the supply chain thereby achieving responsible production and consumption (SDG 12) (Sagel et al. 2022). Modular plants can be set up in places that are economically weaker for operating more efficiently than larger plants and for the creation of more jobs. This would help us achieve decent work and economic growth (SDG 8). Moreover, decentralized manufacturing, supply chain redundancy would improve resistance to natural calamities and supply of raw materials. While designing products, there is a need to implement a circular mindset which results in better product lifecycle reuse and recycling (Aguiar and Jugend 2022).

In the current industrial era, the linear economy which is defined as the sourcing of finished goods directly from the raw materials has been dominating. The conventional linear model does not take important factors such as environment, human resources into consideration. On the other hand, Circular Economy (CE) has proven to be more favourable to the industries as it effectively utilizes the resources, reduces the waste and the financial burden of the industry. Ellen MacArthur's foundation defines CE model as a closed loop of material flow that works on various concepts, some of them being remanufacturing and recycling (Hapuwatte et al. 2022). The CE model creates a balanced effect between economic growth and the environment. CE ensures that always every resource is effectively used for implementing better design and manufacturing methods.

CE acts a pivotal instrument in the field of supply chain management and that directly creates a huge positive growth in any organization (Karman and Pawlowski, 2022). The pandemic has created implications across all industries which has compelled the policymakers to encounter various disruptions regarding the supply chain system. Due to such crises, industries are now focussing on building resilient circular supply chain networks to manage any future challenges (Remko 2020). Therefore, there is an imperative need for industries to find out new disruptive technologies which support supply chains against any future global issues in their transformation towards Industry 4.0 (Ivanov and Dolgui 2021).

Digital technologies are capable of creating positive and negative influence on the industrial segment. Diffusion of digital technologies helps in the improvement of CE which transforms from linear value chains to circular supply chain. This transformation creates an impact on the performance improvement and efficiency of products particularly in reducing waste and optimizing the resources thereby creating economic benefits. Radio Frequency Identification (RFID) has gained recent attention in the field of CE. RFID uses an electromagnetic field and this helps to track the material flow for the recovery of the products by using strategies such as repair, reuse and remanufacture (Visich et al. 2007). Moreover, RFID provides complete information about the product lifecycle as all the products in the cycle have a connected RFID chip that helps to track the products. Internet of Things (IoT) links all the stakeholders and gathers all the information through the use of sensors (Golan et al. 2020). In the context of CE, IOT provides a significant role in the data analysis from different sources. AI tools and techniques help to design much more intelligent systems which can compute more complex algorithms in the field of CE. Data analytics can give a comprehensive outlook of the raw data and embedded data from various machinery or instruments used. Data analytics and big data pave a path for any organization to make better decisions. They also aid in establishing a closed-loop supply chain by monitoring the production and consumption meticulously. These technologies involve a lot of cost and infrastructure which makes many organizations rethink. Research about digital tech and circular supply chain has been growing but it is still in the genesis stage as it has been adopting concepts from various other studies (Khan et al. 2022).

The sudden disruption of the supply chain during the outbreak of COVID 19 points to the urgent need for positive decisions to map and protect supply networks through Artificial Intelligence for forecasting demand and for operations planning, enabling cross-functional agile teamwork with an agile mindset to focus on the single goal, for quicker diagnosis, faster resolving of issues and a centralized view of the entire business, a supply chain control tower would be the best solution. Using advanced analytics, a digital twin simulates the entire supply chain by giving intricate details such as interconnections in the production, supply and warehouse. Moreover, the digital twin reduces the delivery delays by 30% and the idle time by 70% (Pagoropoulosa, 2017).

The suggested techniques maps supply chain network which in turn helps in the motive of this research that is to identify various barriers and to put forth the different challenges faced by paper-cement-sugar industry by addressing the main objective:

RO1. Identifying the barriers in the paper-cement- sugar industry to provide sustainable operations in the field of CE.

RO2. Using TISM model and MICMAC analysis after identifying the barriers which give the interrelationship between them thereby having the potential to revolutionize supply chain.

The study tries to identify the key barriers in the adoption of C.E. which are limited scalability, negative perception towards technology, security challenge and lack of road map for implementing Industry 4.0. The research talks about how digital technologies could help in moving faster towards a more CE future along with its change towards CE that happens in manufacturing industries. The key barriers and reasons for not adopting CE are identified for major industries.

The research paper focuses on a qualitative method known as Total Interpretive Structural Modelling (TISM). TISM is adopted to analyze the barriers, as it supports better qualitative decision making and it provides clarity to understand the relationship between barriers (Schroeder et al., 2018). The advantage of TISM over Artificial neural networking (ANN) and Structural Equation Modelling (SEM) is that the former provides logical relations and the causality of each link while embedded relations in the latter seem to be missing (Mathivathanan et al. 2021). The MICMAC analysis for the classification of the barriers based on strengths is also introduced.

The study is further classified into different sections which gives more detail on the barriers in the adoption of industry 4.0. Section 2 gives an idea about digital technologies and its capability to revolutionise the supply chain industry. Further the TISM application for analysing the supply chain system and the MICMAC analysis for classifying the barriers is also been discussed in Sect. 2.4 and Sect. 3. Further the results and the barriers in Industry 4.0 are elaborated in Sect. 4. The results of the study have been discussed in Sect. 5 followed by the conclusions in Sect. 6.

1.1 Literature review

This section provides an overview on the adoption of barriers in Industry 4.0 and circular economy and the further section talks about the integration of technology between Industry 4.0 and circular economy while the final section highlights the MICMAC analysis and theoretical implications. We summarize our findings in a framework, that shows the barriers of adoption Industry 4.0 technologies in the paper cement industry, this paper contributes by discussing practical expectations of future industry performance when implementing new technologies and provides a background for driving research on the various barriers, the relationship between each barrier and the solutions to tackle the barriers. We have also discussed two major models, TISM & MICMAC. These two analyses haven't been much discussed in other research papers. A detailed analysis on each barrier and the influence it has on Industry 4.0 has also been elaborated. TISM gives a transitive linkage between all the barriers and considers the dynamic relations and linkages between the barriers and establishes a model portraying all the barriers to adoption of Industry 4.0 technologies. MICMAC analysis is done for recognizing influential barriers. This paper has provided to the supply chain literature for addressing the various innovations surrounding Industry 4.0. We also examine TISM's ability to investigate the reasons for various transitive connections.

1.2 Circular economy

In the area of research and development, Industry 4.0 and CE have been the major topics. Industry 4.0 has been in the limelight for some time since it supports technological integration, data tracking, transparency and visibility. It has paved a better pathway for distributed and production networks and has also made sure for better conservation of the environment (Ghisellini et al. 2016). CE is a closed-loop system that has turned multiple conventional businesses into sustainable ones. The study will analyze the barriers which hinder the adoption of Industry 4.0 and C.E. in the Paper Sugar Industry.

The main idea behind CE is to recycle the resources in a closed-loop system where the focus is on waste elimination along with efficient use of resources. This in turn reduces pollution and minimizes carbon footprints (Stumpf et al. 2021). CE is also defined as a financial model focused at long-term value retention. CE has a great foundation in multi-level supply chain systems at various levels including government bodies like European Union and China. In terms of a green economy, CE is potentially the future economic model (Scheel et al. 2020). An example of CE can be seen through Amazon where they have created CE loops to reduce waste and increase recycling which in turn provides various choices for the customers to recycle their products (Singh et al. 2019).

According to Ellen Macarthur Foundation "A structure for an economy that is restorative and regenerative by design is known as a CE". Its foundation is on three major principles namely materials and products in use, regenerating natural systems and designing a system that removes waste. Cradle to cradle model is a very important part of CE. It creates a complete system that is free of waste by using the products in a regenerative manner where the quality does not reduce (Snellinx et al. 2021). The model has a connection with the Industrial ecology model which states that both industries and the environment cannot be separated as information and energy take place with the help of the environment. Using CE, the quality of the material would remain good for a long time and sustainable manufacturing is a prime requirement of CE (Ranta et al. 2018). Reverse Logistics and CE practices within a supply chain are the sustainable practices that should be followed within any organization (Kazancoglu et al. 2018). Industries should develop the ability for reducing scrap material, utilizing resources efficiently and improving product quality for sustainable operations (Pourjavad and Shahin 2018).

1.3 Technology integration between industry 4.0 and Circular Economy

Effectively organizing and allocating resources on time-to-time basis by various industries can be done with the help of Industry 4.0 technologies. Collection of Data, Integration of Data and Analysis of Data are the three main pillars of Industry 4.0. RFID and IoT are a few applications of data collection (Pagoropoulos, 2017). Relational Data Base Management Systems (RDBMS) which integrates different data sources supports the main objectives of Industry 4.0 and CE since they handle the information extracted from systems such as Customer Relationship Management (CRM) using technologies such as IoT and Enterprise Resource Planning (ERP). Product Lifecycle Management (PLM) systems integrates important data across life cycles and stakeholders which in turn interconnects Industry 4.0 and CE (Psarommatis and May 2022). Big Data analysis and ML play a crucial role in the development of Industry 4.0 and CE since they can compute and process large data and also predicts future modelling. They also make sure that the materials are in a closed-loop system which further strengthens the concept of CE. For manufacturing decisions and sustainable operations, there needs to be a proper balance between Industry 4.0 and CE technologies. The technological advancement in supply chain and resource management strengthens the transition towards the circular economy. This also leads to an effective resilient and sustainable supply chain which in turn provides an opportunity for expanding CE further (Nandi et al. 2021).

1.4 Barriers identified

Despite the advancement of these technologies, many industries are hesitant to adopt the technologies. Industry 4.0 technologies weren't implemented by many industries due to a lack of efficient leadership. Support from the senior management level is vital for promoting sustainable strategies throughout any organization. This approach plays a very crucial role in achieving their long-time goals. When these technologies are successfully implemented it would make employees make a shift from linear to circular economy. Many industries are reluctant to implement these technologies due to lack of infrastructure, security challenges, disruption to existing jobs, limited scalability and unclear government policy. Due to lack of proper investment, many industries are not able to bring in new technologies such as Machine Learning, Big Data and Artificial Intelligence (Ball et al. 2018). Thirteen major barriers were figured out in this study through various expert opinions and literature reviews.

1.4.1 Lack of knowledge expertise and awareness on digital technology implementation

Proactive plans are required to implement digitalization at all organization hierarches throughout the supply chain and the lack of standard tools and business models is a challenge for Industry 4.0 (Manavalan and Jayakrishna 2019). In an international market, several organizations aren't able to capitalize on their prospects as they lack the fundamental principles of industry 4.0 (Lopes de Sousa Jabbour et al. 2018) and thus do not realize the advantages of implementing Industry 4.0 principles which has an adverse effect on environment which would in return save them a lot of money (Jaeger and Upadhya, 2020; Kumar et al. 2021a, b).

1.4.2 Lack of infrastructure

In the time of increasing technological standards, an updated system infrastructure is required which can handle and integrate the different components or devices (Jaeger and Upadhyay 2020). The lack of high-quality infrastructural resources plays an important role in moving forward in Industry 4.0 implementation (Rajput and Singh 2019). With the lack of quality system and infrastructure, interfacing different components in the system would be a challenge thereby making it difficult to interact with the physical world. Lack of infrastructure can also cause obstructions which in turn leads to overall delays in the supply chain network (Biswasa and Gupta, 2019) which in turn gives rise to internal software attacks which leads to change in information which the user receives.

1.4.3 Security challenge

Hacking, incorrect information pose a lot of security challenges as they are embedded with a lot of critical information. Security and technical vulnerability of the information are some of the main technological barriers. According to researchers, there are a lot of transactions which happen in the supply chain network in which the authentication details are available which in turn tends to be insecure. As a result, it could also lead to significant privacy concerns for the users. Due to lack of security, further progress in a business environment is limited. Intensified security would be the prime challenge to give a secure flow of data and information (Mathivathanan et al. 2021).

1.4.4 The negative perception towards new technology adoption

Negative perception largely focuses on the public image which plays a large role in adopting or implementing a new technology towards Industry 4.0 development. Of late, it has been a negative perception in adopting new technologies mainly because of the lack of security involved in the supply chain which in turn gives rise to other illegal activities which in turn leads to hesitation in organizations adopting new technologies. Further, there is a significant relationship between the barriers, security and adopting new technologies which require a strong attention to overcome (Lohmer and Lasch 2020). While security acts as the mediator barrier, it is also known that technology access, i.e., lack of proper IT resources could also be a potential challenge to overcome the negative impact of adopting new technologies.

1.4.5 Immaturity of technology

Due to lack of development in technology, software threat arises which leads to cyber-attacks and also economic and financial losses. Considering the supply chain as global, we cannot expect everyone to be equipped with the latest technologies (Luthra and Mangla 2018). This gives rise to the question as to how to establish or adopt on large scale. If there are large complex transactions taking place, high-powered systems are required since low-powered systems can cause a lot of delays (Karmaker et al. 2021). Many industries are yet to equip themselves with the latest technologies or some industries are unaware of the latest tools which have had an indirect impact on security challenges and negative perception towards technology (Kouhizadeh et al. 2021).

1.4.6 Unclear government policy

Government support plays an important role in adopting CE techniques in connection with sustainable management. Governments would not be in favor of promoting the latest technology innovations with regards to sustainable supply chain practices (Luthra et al. 2019).Governments also fail to encourage the promotion of industry 4.0 despite the availability of many resources due to plenty of rules and regulations. Further, in developing countries, governmental incentives and support would be a substantial barrier in the development of Industry 4.0 technologies if not provided (Mittal et al. 2018).

1.4.7 Dependent on 3rd party technology providers

For the efficient implementation of Industry 4.0, high-quality real-time data would be vital. Since the IT resources and infrastructure are not equipped with the latest technologies, the dependency on third-party providers becomes more prominent (Yadav et al. 2020) which in turn has led to plenty of questions and concerns regarding system safety and security.

1.4.8 Limited scalability

Limited scalability is one of the important barriers which limit the technology for widespread production use. Due to limited scalability, there is vulnerability and insecurity of the technical resources available for further use. Most business models identify scalability as the major challenge (Tönnissen and Teuteberg 2020). One of the main reasons for limited scalability could be the lack of development in technology towards Industry 4.0 implementation.

1.4.9 Lack of roadmap for successful implementation of industry 4.0

For the efficient flow of Industry 4.0 with C.E., a well-defined strategy would be required. The need for a well-defined strategy is to understand the principles and fundamentals of Industry 4.0 implementation. Wholistic consideration (both technological and financial) is required while choosing the strategy. Ineffective planning could be the major reason for not executing the right methods and methodologies for the successful execution of Industry 4.0 (Swan 2018).

1.4.10 Disruption to existing jobs

With the rise in technology, employees fear to equip themselves with the latest skills due to fear of loss of jobs thereby having themselves in a shell by not updating with the increasing technological standards which in turn indirectly affects the pathway for Industry 4.0 implementation (Luthra et al. 2019). Lack of awareness with regards to sustainability and adapting to the needs of the supply chain could be possible reasons for job threat and disruption (Suarez-Eiroa et al., 2021).

1.4.11 Difficulty and complexity in changing organizational culture

Organizations have been finding it very difficult to change their existing culture or policies for Industry 4.0 implementation. More often, organizations are having short-term goals requiring immediate results which limits them to further change in policies thereby not having a change in their workflow (Tönnissen and Teuteberg 2020). Organizational culture could involve the behaviour of the respective teams and also a set of guidelines and procedures to be followed as part of their work culture. Organizations need to come up with the change in policies or define a new set of guidelines and also would need to develop a better understanding within themselves so that it would create an effective change in Industry 4.0 implementation. With the rapid advancement in technologies, there could be a need for change in systems within the organizations (Swan 2018).

1.4.12 Investment cost

Investment cost comes as a major challenge in Industry 4.0 implementation. A huge investment is required in adopting the latest technologies available related to Industry 4.0 (Raj et al., 2019).When the cost of investing is more, investors often worry about the security of the transactions which would lead to disinvestment. Cost also comes into the picture when organizations try to convert the information collected through the supply chains to new systems. Most of the industries are tight with financial investments and assets and in turn are not able to avail the latest resources. When a new technology is adopted, a lot of support is required in the hardware and software domain. The cost associated with the maintenance increases with additional investments which would prove very costly not only for organizations but also for the supporting people and investors (Luthra and Mangla 2018).

1.4.13 Unclear benefits

Due to lack of financial resources and improper planning, there is reluctance from team management in giving benefits and supporting the activities relating to Industry 4.0 (Biswasa and Gupta, 2019). The lack of long-term commitment from higher management to sustainability practices creates a problem among individuals and also affects the supply chain cycle. One of the reasons for not providing proper benefits would be the use of disruptive technology which would be mainly for companies that are risk-prone in adopting new technologies. The lack of a reward system could also be a reason for unclear benefits. The support and commitment from the higher management are very essential

Table 1 List of barriers identified

Barrier	Barrier	Reference
B1	Lack of knowledge expertise and awareness on digital technology implementation	Akpan et al. (2022); Kamble et al. (2019); Massaro et al. (2021); Grafström and Aasma (2021); Chen (2021)
B2	Lack of infrastructure	Guerra et al. (2021); Ciliberto et al. (2021); Nogueira et al. (2020); Kumar and Chopra (2022); Demestichas and Daskalakis (2020).
B3	Security Challenge	Biswas and Gupta, (2019); Bag et al. (2021); Bressanelli et al. (2019); Yildizbasi (2021); Dwivedi and Paul (2022)
B4	The negative perception towards new technology adoption	Swan (2018); Kumar et al. (2021a, b; Saidani (2022); Kolade et al. (2022); Cicculло (2021)
B5	Immaturity of technology	Kumar et al. (2022); De Giovanni (2022); Erol et al. (2021); Etemadi et al. (2021); Prause (2019)
B6	Unclear Government Policy	Toufaily et al. (2021); Schedler et al. (2019); Andrews et al. (2018); Raj et al. (2020a, b)
B7	Dependent on 3rd party technology providers	Janssen et al. (2020); Ritz et al. (2019); Ghobakhloo and Ching (2019); Maesa and Mori (2020)
B8	Limited scalability	Biswas and Gupta (2019); Niederhauser et al. (2018); Chouki et al. (2020); AlHogail et al. (2018)
B9	Lack of roadmap for successful implementation of Industry 4.0	Ball et al. (2018); Rajput and Singh (2019); Butt (2020); Hidayatnoet al. (2019); Cotrino et al. (2020)
B10	Disruption to existing jobs	Seet et al. (2018); Vu and Lim (2022); Balsmeier and Woerter (2019); Van Veldhoven and Vanthienen (2022); Prause (2019).
B11	Difficulty and complexity in changing organizational culture	Isensee et al. (2020); Laurenza et al. (2018); Priyono et al. (2020)
B12	Investment cost	Skare and Soriano et al. (2021); Brambilla and Tortarolo (2018)
B13	Unclear benefits	Shepherd et al. (2020); Ghobakhloo et al. (2020); Ferreira et al. (2019); Kirchherr et al. (2022)

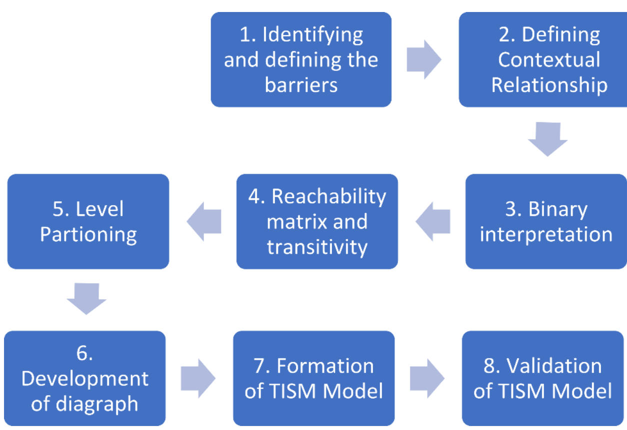

Fig. 1 Analysis of barriers (TISM Model):

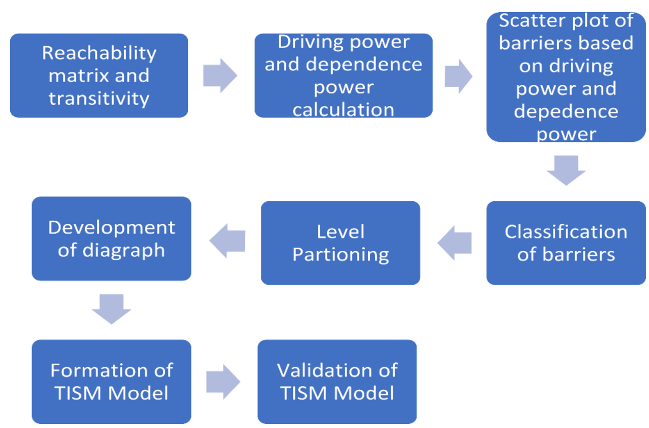

Fig. 2 MICMAC Analysis:

in creating a strong bond among individuals which would be very essential in Industry 4.0 implementation (Mittal et al. 2018). The barriers identified are listed in Table 1.

1.5 TISM and MICMAC analysis in identifying the barriers

Rapid advances in Industry 4.0 technologies and the increasing benefits they bring to the global supply chain will enable enterprises to exercise them within their current infrastructure. After analyzing the connections between failures, administrators can take appropriate decisions for successful implementation of Industry 4.0. While existing literature aims to provide a detailed analysis of barriers and test specific hypotheses using quantitative methods, it has built a theory and successfully adopted digital technology in paper sugar cement. There are no studies showing the interrelationships between barriers that affect the industry.

This paper uses a relationship-based TISM approach which leverages the judgements of experts from various pertinent industries to create a model of the barriers identified for the adoption of digital technologies in Industry 4.0. Aims to fill the gap in construction theory. TISM, like Pareto 8020's Law, helps implementation managers prioritize 20% of causal barriers which influences 80% of recruitment procedures for gaining better insights into the barrier removal process. The Technology Acceptance Model (TAM), a common approach done by scholars studying the adoption of new technologies to measure the business goals of technology adoption. While TAM gives perception on behavioral aspects, TISM provides relationships between barriers that TAM cannot address. In contrast to structural models that are developed through utilizing methods like SEM and ANN, TISM model based on system theory make decision through enhanced explanations of the relations embedded in the system (Sushil 2012). TISM is chosen for this study, in comparison to alternate methods like DEMATEL and AHP, because it props up the interrelationship between the barriers for each pair-wise comparison through rendering the fundamental reasoning, as a result it allows to comprehend the complete model (Vimal et al. 2022). Also, TISM attempts to create a planned conceptual framework to overwhelm the drawbacks of conventional Interpretive Structural Modelling (ISM) through elucidating the transitive links as well as the cause for this links among the elements of model developed based on ISM. An improvement of conventional ISM is TISM has been utilized for the development of performance model based on the contextual relationship to impede the barriers in the adoption of digital technologies in paper-cement-sugar manufacturing circular economy network (Yadav 2014).

TISM is an interpretative practice of modelling distinct relationship based on the decisions of team of experts concerning the relations among the various barriers participated (Singh and Sushil 2013). This approach assists in depicting the interactions in diagraph among the barriers (Sindhwani and Malhotra 2017). An arrow is used to depict the relationship among the barriers based on the direction and the hierarchical order. The position of levels in diagraph eventually helps in determining the significant barriers and the contextual relationships among any two barriers are explained upon the connecting arrow is one of the advancements from the traditional ISM (Shibin et al. 2017). The other benefits from TISM are through critical reasoning the transitive relationship could be retraced again. In contrary to ISM, TISM examine the real cause for the transitivity if existing through judgement from the expert and counts merely the efficient transitive links for the model development will provide a better reliable analysis among the barriers. Additionally, in TISM the barriers are categorized with MICMAC (Matriced'Impacts Croises-Multipication Applique' and Classment). The barriers relationship is not equal always - few could be powerful while rest could be frail. The models success is better only if the relationships between the barriers are stronger. MICMAC analysis helps in classifying the barriers and to determine the essential barrier that led the developed structural model based on the mutual dependence and dominance power between the barriers. Hence in this study TISM-MICMAC approach was used.

1.6 Research gaps identified

The following gaps were figured out which were based on the literature review:

The literature available on CE focuses on the ideology and benefits of CE. An in-depth analysis would be required which would give the feasibility-related issues concerning the application of CE and industry 4.0.

- Previous studies have focussed more on the integration of data and data analysis. There has been less attention given to technological aspects. In this research paper, we would be focussing on the impact of digital technologies and how it would play a role in developing CE and industry 4.0.
- Previous studies have focussed on Industry 4.0 technologies and CE separately. Therefore, for more understanding of the barriers, a study combining Circular Economy and Industry 4.0 concepts would be essential.

With the rapid advancement of Industry 4.0 technologies and the increased benefits that it offers to supply chains globally, it would be viable for organizations to implement Industry 4.0 technologies within their existing framework as it provides them with a lot of benefits. Managers can take proper decisions towards the successful adoption of Industry 4.0 by analyzing the relationships between barriers. While existing literature aims to provide a comprehensive analysis of barriers and test specific hypotheses using quantitative methods, it has built a theory and successfully adopted digital technology in paper sugar cement. There are no studies showing the interrelationships between barriers that affect the industry.

2 Methodology

2.1 TISM and MICMAC to analyze barriers of industry 4.0 technologies adoption

This article TISM approach is adopted for establishing a relationship-based model which is succeeded by MICMAC analysis for classifying the barriers with respect to their potential. The various steps for incorporating the building of the TISM model has been detailed in the next section. Next, by using MICMAC analysis the linkages which are dependant and independent elements in the system are identified. Several step wise procedures in TISM methodology are then examined.

2.1.1 Application of TISM methodology

By defining the various steps and evolving the contextual relationship-based model, the TISM model is developed to study the barriers in the implementation of Industry 4.0 technologies. The validation of TISM model is described in each step with the data collected.

Step 1: The first step is to identify the barriers from existing literature and define the elements associated with the barriers. The elements which are defined from the barriers are part of TISM in which the relationships are to be modelled (Mamounis et al. 2022).

Thirteen barriers are identified in the implementation of Industry 4.0 technologies. The barriers identified are then floated among the experts for getting an opinion. The study required experts to provide 156 paired relationships since the study was more of a qualitative analysis. Along with the paired relationships, the experts had to provide the logic and meaning for each of their responses to the relationship.

An expert team was constituted with ten experts from the manufacturing sector and five from the automotive sector. These people were highly qualified in areas of supply chain and logistics having experience of more than 15 years. Experts were also from reputed academic institutions having vast understanding in the area of Industry 4.0 and related technologies. A detailed explanation of each barrier was given to the experts who were very versed in the field of the supply chain. This was followed by a brainstorming session with the experts. The expert team provided the inputs for the TISM model.

Step 2: The contextual relationship of the barriers is defined. The pair-wise interpretation between each barrier is identified by in-cooperating the suggestions given by proficient leaders, for example, barrier B3 influencing barrier B4. For our reference, the reason for barrier B3 influencing barrier B4 is noted in the base matrix with the help of experts in the form of a survey along with reasons for each explanation which further gives a detailed view. This in turn gives a contextual relationship between the barriers. Personal discussions with the experts gave more insight for analyzing pairwise relationship among the barriers which further strengthened the knowledge. The information given by the experts was then noted in the form of table containing rows and columns in which the rows represent the pairwise relationship between each barrier as listed in Table 2.

A total of thirteen barriers have been considered. Therefore, the total number of rows is $13 \times 12 = 156$. The table matrix was formed by discussing the 156 relationships with the experts. The corresponding 156 connections was reviewed with the leaders thereby forming knowledge.

matrix. For interpreting the elements of the table, we required more than 50% responses to.

compare the elements and those elements were depicted as "Yes". If the response was less than 50%, the corresponding elements were depicted as "No". The elements which had a contextual relationship, i.e., the elements which were depicted as "Yes" were analyzed by the opinions.

given by the experts and it was used for calculations that were tabulated.

Step 3: The next step is the binary interpretation of pair-wise comparisons. Between each pair-wise relationship, the logical relationship of respective barriers was displayed as n×n matrix, where n stands for number of barriers. The value "1" or "0" was entered in every $(i,j)^{th}$ cell, based on effect of barrier Bi over Bj. The value "1" indicates influence of barrier Bi on Bj. The value "0" indicates that there is no relationship. In this paper, we had developed a 13×13 matrix in which there were $13 \times 12 = 156$ pair-wise comparisons. The initial matrix was prepared based on the knowledge base and information given by experts. Each barrier is compared with each other to find if there is any relationship existing between the barriers. The value "1" is written if there is any relationship between the barriers. The value "0" is written if there is no relationship between the barriers. The values are tabulated, and initial matrix is formed as displayed in Table 3. In the initial matrix, the values depicted as "1" are showed up in green which are direct relationship. Diagonal values are showed up in yellow and these values are assumed as "1".

Step 4: In the next step, we form the reachability matrix and we check for transitivity as shown in Tables 2 and 4. Once the initial reachability matrix is formed (matrix formed from a logical relationship), the matrix is cross-checked to see if there is any transitivity between the elements is established on the transitivity rule. The transitivity rule states that if Bx has an influence on By and By influences Bz, then Bx will influence Bz. Likewise, we check for transitivity for each element. The elements which show transitivity are renamed as "transitive link". A barrier may have one or more transitive relationships. An example of transitivity from our study is the relation between the barriers B1(lack of expertise and knowledge) and B3(high initial investment). The initial reachability matrix showed no relationship between these barriers. After the TISM model analysis, we found that there exists a relationship between these barriers hence

Table 2 Final Reachability Matrix

Barrier		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Lack of expertise and knowledge	B1	1	1	1	0	1	1	1	1	1	1	0	1	1
Difficulty in changing organizational culture	B2	0	1	0	0	0	0	0	0	0	0	0	0	0
High initial investment	B3	0	1	1	0	0	1	1	0	0	0	0	0	0
Lack of infrastructure	B4	0	0	1	1	1	1	1	0	1	0	0	1	1
Security Challenge	B5	1	1	0	0	1	1	1	1	1	1	0	0	1
Negative perception towards technology	B6	0	1	0	0	0	1	0	0	0	0	0	0	0
Limited Scalability	B7	0	0	1	0	0	1	1	0	0	0	0	0	0
Immaturity of Technology	B8	0	1	1	0	1	1	1	1	1	1	0	1	1
Lack of roadmap for implementing 4.0	B9	1	1	0	0	1	1	0	1	1	1	0	0	1
Unclear benefits	B10	0	0	0	0	0	0	0	0	0	1	0	0	0
Unclear Government Policy	B11	1	1	0	0	1	1	0	1	1	1	1	1	0
Disruption to existing jobs	B12	0	1	0	0	0	1	0	0	0	0	0	1	0
Dependent on 3rd party	B13	1	1	1	0	1	1	1	1	1	1	0	1	1

depicting the transitivity in the final reachability matrix table. In the table, we consider the transitive relationship between the barriers while the other values remain the same. The initial reachability matrix is formed by having binary values which tell about the relationship of the barriers.

The focus of the transitivity check is to recognize the indirect relationships. Final reachability matrix represents the transitive elements as shown. The transitivity between each barrier is checked and if transitivity exists, it is highlighted and marked in green. The transitivity is determined by the transitivity rule. The experts are approached once again to analyse the transitive elements and their opinions are noted to update the matrix. The ineffective transitive links are eliminated after discussion with experts which outlines the TISM model.

More knowledge on transitive links were found with the help of experts. The transitive links are discussed with the experts and we also discuss the existing transitive links thereby updating the knowledge base.

Step 5: In the next step, level partitioning is done. The level-wise placement of barriers is identified by doing level partitioning. There are three sets determined by level partitioning. They are the reachability set, antecedent set and intersection set which are established on the dependence power of each barrier. For example, the barriers which are in the top position do not cross their level. A similar approach was followed to figure out the magnitude of each barrier. As a result, these levels are the foundation for the digraph and TISM model. The final reachability matrix has been explained in the previous step which is formed with the direct relationships of the barriers along with the effective transitive links. The reachability antecedent and the intersection sets for every barrier are got from the final reachability matrix. The levels of the barriers are determined from the intersection and reachability set. The barrier that possesses equal intersection set and reachability set are placed in Level 1 which is the highest level. These barriers are subsequently withdrawn from the list of barriers and the iteration process is continued. When the barriers have their designated levels, the iteration process stops. All the barriers would have their level assigned after four iterations.

From the final reachability matrix, driving and dependence power is formed. Based on them, the reachability, antecedent and intersection set are formed which determines the level of barriers. The reachability set is formed based on the driving power and the antecedent set is formed based on the dependence power. The intersection set is the combination of reachability set and antecedent set. Level 1 is the topmost barrier where reachability and intersection set are equal. The process is continued till the level of all the barriers are known. The levels of each barrier are shown in Table 5.

Table 3 Initial Reachability Matrix

Barrier		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Lack of expertise and knowledge	B1	1	1	0	0	1	1	0	0	0	1	0	0	1
Difficulty in changing organizational culture	B2	0	1	0	0	0	0	0	0	0	0	0	0	0
High initial investment	B3	0	0	1	0	0	1	1	0	0	0	0	0	0
Lack of infrastructure	B4	0	0	1	1	0	0	1	0	0	0	0	0	1
Security Challenge	B5	0	0	0	0	1	1	0	1	1	0	0	0	0
Negative perception towards technology	B6	0	1	0	0	0	1	0	0	0	0	0	0	0
Limited Scalability	B7	0	0	1	0	0	0	1	0	0	0	0	0	0
Immaturity of Technology	B8	0	0	0	0	1	1	1	1	0	1	0	0	1
Lack of roadmap for implementing 4.0	B9	1	1	0	0	1	1	0	0	1	1	0	0	0
Unclear benefits	B10	0	0	0	0	0	0	0	0	0	1	0	0	0
Unclear Government Policy	B11	0	0	0	0	1	1	0	0	1	0	1	1	0
Disruption to existing jobs	B12	0	0	0	0	0	1	0	0	0	0	0	1	0
Dependent on 3rd party	B13	0	0	1	0	1	0	1	0	1	0	0	1	1

Step 6: As we continue the process, the next step is the development of digraph. Digraph is a graph that represents the barriers graphically based on the levels of the barriers. Diagraph also represents the links of the barriers which are depicted with arcs or pointers. (Farooque et al. 2022). First, the direct relationship between the barriers is represented through continuous arcs which is the basic version of the digraph. Secondly, the transitive links are considered. The transitive links which are effective and have a significant relationship are depicted using dashed arcs in the digraph. As a result, the final TISM model is derived. The digraph is mainly based on the levels of the barriers. The thirteen barriers are organized based on their levels graphically which is derived from the level partition. From the final reachability matrix, the relationships between the barriers are interpreted by arrows in diagraph. Figure 3 represents the diagraph showing the direct relationship between the barriers in continuous links and transitive elements in dotted arcs.

Step 7: Next step involves the formation of the TISM model. The details present in the knowledge base is displayed in the corresponding connections of digraph. The digraph with the respective links forming the TISM model is shown in the Fig. 4.

Step 8: The next step is the validation of TISM model. TISM model has been formed by limited number answers. The reason for the limited number of responses was that the professionals had to spend a lot of time on pairwise comparisons and justify the interpretation of pairwise comparisons. In our study, they were asked to give $13 \times 12 = 156$ comparisons. This was a time-consuming process for the experts since they had to give logical interpretations for 156 pairs. Few volunteers volunteered for the process. Thus, the process was very time-consuming for the experts. When the TISM model is developed, the number of links was reduced. This reduction in links made it easier for experts to interpret the logical relationship since the time consumed for the process was less. As a result, a larger group of experts were contacted to assess the developed model. In this process, the experts had been told to rate the pairwise relationship on a scale from 1 to 5 in which 1 was the rating meaning they had not agreed and 5 was the rating meaning they agree. The average score for each link to be accepted was there and for the TISM model, the model is approved if the mean score is over three for all links. The accepted interpretations are presented in Table 6.

2.2 MICMAC analysis

The next step is the MICMAC analysis. In MICMAC analysis, the variables and elements are analyzed based on their impact. The important or the main barriers which influence the adoption of digital technologies are analyzed in

Table 4 Final Reachability Matrix Validated

Barrier		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Lack of expertise and knowledge	B1	1	1	0	0	1	1	0	0	0	1	0	0	1
Difficulty in changing organizational culture	B2	0	1	0	0	0	0	0	0	0	0	0	0	0
High initial investment	B3	0	0	1	0	0	1	1	0	0	0	0	0	0
Lack of infrastructure	B4	0	0	1	1	0	0	1	0	0	0	0	0	1
Security Challenge	B5	0	0	0	0	1	1	0	1	1	0	0	0	1
Negative perception towards technology	B6	0	1	0	0	0	1	0	0	0	0	0	0	0
Limited Scalability	B7	0	0	1	0	0	0	1	0	0	0	0	0	0
Immaturity of Technology	B8	0	0	1	0	1	1	1	1	1	1	0	0	1
Lack of roadmap for implementing 4.0	B9	1	1	0	0	1	1	0	0	1	1	0	0	1
Unclear benefits	B10	0	0	0	0	0	0	0	0	0	1	0	0	0
Unclear Government Policy	B11	0	0	0	0	1	1	0	0	1	0	1	1	0
Disruption to existing jobs	B12	0	1	0	0	0	1	0	0	0	0	0	1	0
Dependent on 3rd party	B13	0	0	1	0	1	1	1	0	1	0	0	1	1

MICMAC. MICMAC analysis is based on the driving and dependence power of every barrier (Modgil et al. 2022). The detailed flow of MICMAC analysis till the validation of TISM model is as shown in Fig. 2. It provides a graphical representation that comprises four quadrants namely autonomous, dependent, linkage and driving. The four quadrants are based on the driving and dependence power of every barrier. The driving and dependence power is formed based on the final reachability matrix. The total addition of columns and rows of the final reachability matrix gives the dependence power and driving power of each barrier. For example, if barrier 3 is considered, the driving power is three and the dependence power is five. A graph is plotted against them for each barrier. The graph is plotted in accordance with the four quadrants as shown in Fig. 5. The driving and dependence power of each barrier is found as shown in Table 5.

The first quadrant comprises the autonomous elements. Autonomous elements are elements in which the barriers have the minimum driving and dependence powers. The dependent elements comprise of the second quadrant. The quadrant has barriers that are very much dependent. The third quadrant consists of the linkage elements. The quadrant is associated with barriers that have high driving and dependence power. The barriers in the third quadrant are unstable and disturb the full system. The fourth quadrant consists of the driving elements. The barriers in the fourth quadrant have powerful driving power but have feeble dependence power.

3 Results and discussion

The TISM model was then developed with the necessary transitive links and arranging the barriers according to their respective levels. The TISM model consists of a seven-level model (Table 7).

Level 1 - The barriers B2, i.e., difficulty in changing organizational culture, barrier B7, i.e., limited scalability and barrier B10, i.e., unclear benefits were at level 1 of the TISM model. This shows that these barriers have less influence on the adoption of digital technologies. These barriers might not be very important but might be influenced by other factors. The limited availability of resources makes it difficult to change the organizational culture (Mittal et al. 2018).

Level 2 – This level consists of barrier B6, i.e., negative perception towards technology. The public image plays a role in the negative approach towards the implementation of digital technologies thus making it a barrier (Modgil et al. 2022).

Table 5 Driving power and dependence of barriers

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Driving Power	6	1	3	4	5	2	2	8	7	1	5	3	7
Dependence Power	2	5	5	1	6	9	5	2	5	4	1	3	6

Level 3 - Lack of security also gives a negative perception in adopting digital technologies which makes it a barrier placed at level 3. The other barriers in level 3 are barrier B3, i.e., high initial investment and barrier B12, i.e., disruption to existing jobs. Investment cost plays a major role in Industry 4.0 implementation. Since most organizations are not equipped with the latest technologies, a high initial investment is required. Investment is also related to maintenance costs when a new technology is adopted. Disruption in jobs acts as a barrier mainly because of the reason that the employees are not updated with the advancement in technologies. This affects the implementation of Industry 4.0. Another reason for disruption in jobs could be due to a lack of awareness of Industry 4.0 and sustainability (Farooque et al. 2022).

Level 4 - The fourth level of the TISM model consists of barrier B13, i.e., dependent on 3rd party technology providers. The dependency on 3rd party rises since the organizations are not updated with the latest technologies. High-quality data with the latest technologies are needed for the effective execution of Industry 4.0. With the dependency on 3rd party, security also comes into the picture (Mamounis et al. 2022).

Level 5 - The fifth level of the TISM model consists of barriers B1, i.e., lack of expertise and knowledge and barrier B4 i.e., lack of infrastructure. In the time of increasing technological standards, an updated system infrastructure is required which can handle and integrate the different components or devices. The lack of high-quality infrastructural resources plays an important role in moving forward in Industry 4.0 implementation (Rajput and Singh 2019).With the lack of quality system and infrastructure, interfacing different components in the system would be a challenge thereby making it difficult to interact with the physical world. Proactive plans are required to implement digitalization at all organization levels throughout the supply chain and the lack of standard tools and business models is a challenge for Industry 4.0. Industries are unable to utilize their resources in market since they lack the basic knowledge of Industry 4.0.

Level 6 – This level consists of barrier B9, i.e., lack of a roadmap for implementing 4.0. This is one of the critical barriers since it provides valuable interlinks to the system when it connects to other levels. In many companies Industry 4.0 investment in such companies exceeds the turnover of SMEs (< 50 million dollars), demonstrating the limited access SMEs which makes access to these technologies extremely difficult. Strategized planning and proper framework are needed for the execution of Industry 4.0 and C.E. The purpose of a clearly defined approach is to understand the principles and fundamentals of Industry 4.0 implementation. Wholistic consideration (both technological and

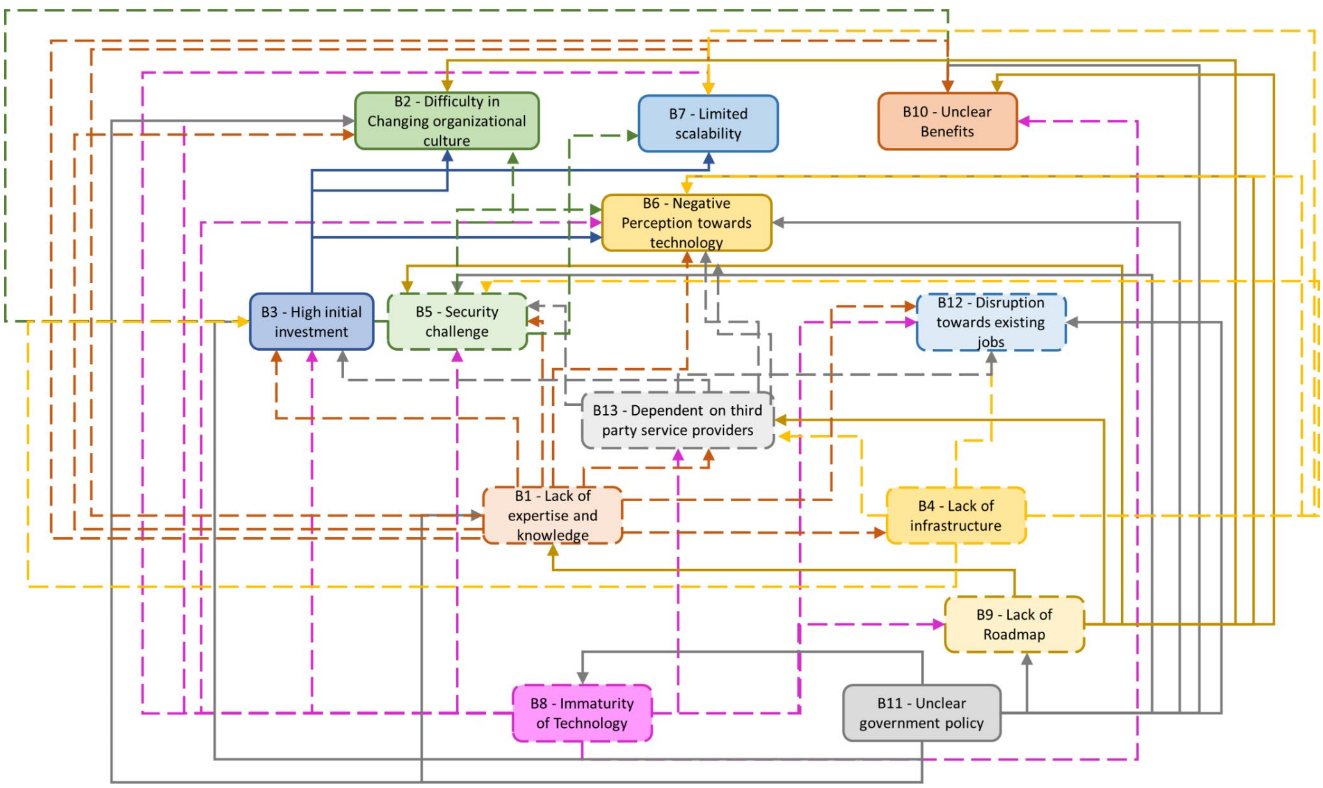

Fig. 3 Digraph showing both direct and transitive links (TISM model)

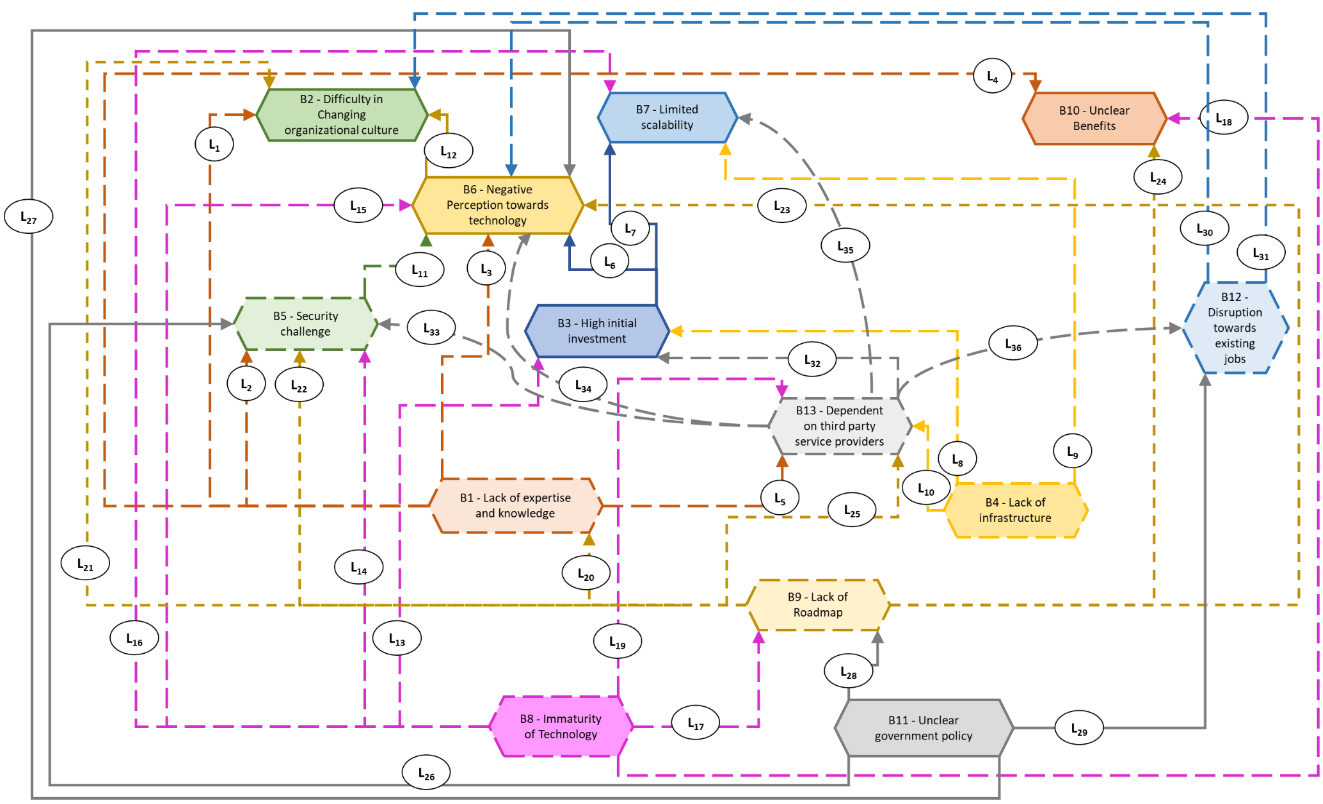

Fig. 4 Total interpretive structural model

Table 6 Validated Interpretations

S.No.	Barrier link	Interpretation
L1	B1-B2	Lack of expertise hinders change in organization
L2	B1-B5	Decreases Security
L3	B1-B6	Increases Negative Perception
L4	B1-B10	Affects Benefits
L5	B1-B13	Increases Dependency
L6	B3-B6	Influences Negative Perception
L7	B3-B7	Hinders Scalability
L8	B4-B3	Influences High Investment
L9	B4-B7	Decreases Scalability
L10	B4-B13	Increases Dependency
L11	B5-B6	Increases Negative Perception
L12	B6-B2	Hinders Organizational Change
L13	B8-B3	Immature Technology influences high initial investment
L14	B8-B5	Increases Security
L15	B8-B6	Increases Negative Perception
L16	B8-B7	Hinders Scalability
L17	B8-B9	Hinders Roadmap
L18	B8- B10	Decreases Benefits
L19	B8-B13	Immature Technology affects 3rd party
L20	B9- B1	Influences knowledge
L21	B9- B2	Improper planning affects change in organizational culture
L22	B9-B5	Hinders Security
L23	B9- B6	Increases Negative Perception
L24	B9-B10	Hinders Benefits
L25	B9-B13	Influences dependency
L26	B11-B5	Hinders Security
L27	B11-B6	Increases Negative Perception
L28	B11-B9	Affects Implementation
L29	B11-B12	Increases Disruption
L30	B12-B2	Affects Organizational Change
L31	B12-B6	Influences Negative Perception
L32	B13-B3	Influences High Investment
L33	B13-B5	Hinders Security
L34	B13- B6	Influences Negative Perception
L35	B13-B7	Influences Scalability
L36	B13-B12	Increases Disruption

financial) is required while choosing the strategy. Ineffective planning could be the major reason for not executing the right methods and strategies for the effective execution of Industry 4.0 (Swan 2018).

***Level** 7 -* The seventh level of the TISM model which is the final level consists of barriers B8 i.e., immaturity of the technology and barrier B11 i.e., unclear government policy. These are the most dominant barriers which stand as a wall to the execution of digital technologies in Industry 4.0. When industries are unaware of the latest technologies available, it is not much put into use and is immature. The organizations have very little information on how the latest technologies could benefit them in the future. This in turn affects the execution cycle of implementing digital technologies in industry 4.0. Due to lack of financial resources and improper planning, there is reluctance from team management in giving benefits and supporting the activities relating to Industry 4.0 (Biswasa and Gupta, 2019). The lack of long-term commitment from higher management to sustainability practices creates a problem among individuals and also affects the supply chain cycle. One of the reasons for not providing proper benefits would be the use of disruptive technology which would be mainly for companies that are risk-prone in adopting new technologies. The support from the higher management committee is crucial in developing the bond in individuals to implement digital technologies in Industry 4.0 (Jhariya et al. 2022).

Due to lack of financial resources and improper planning, there is reluctance from team management in giving benefits and supporting the activities relating to Industry 4.0 (Biswasa and Gupta, 2019). The lack of long-term commitment from higher management to sustainability practices creates a problem among individuals and also affects the supply chain cycle. One of the reasons for not providing proper benefits would be the use of disruptive technology which would be mainly for companies that are risk-prone in adopting new technologies. The lack of a reward system could also be a reason for unclear benefits. The support and commitment from the higher management are very essential in creating a strong bond among individuals which would be very essential in Industry 4.0 implementation (Mittal et al. 2018). Our research aims to throw light on these barriers and hope for organizations to adopt digital technologies in Industry 4.0.

MICMAC analysis refers to the cross-multiplicative influence matrix applied to rankings, allowing us to identify and analyse the driving forces and dependencies of important attributes of our interpretive model. MICMAC is an indirect classification technique for comparative analysis of the relationship range of each attribute. The MICMAC analysis is established graphically which gives the relationship between driving and dependence power. It gives the relationship and the importance of barriers (WCED 1987). The graphical diagram consists of four quadrants as explained earlier. The quadrant which has very less impact on the system is the first quadrant, i.e., the autonomous quadrant. These barriers have the least impact and have fewer links in the system mainly due to the low driving and dependence power. They do not affect the system in any manner. If any barriers come in the 1st quadrant, i.e., if there are any autonomous elements, they have to be considered as driving variables which should be given the most priority.

The analysis comprises of four quadrants. The second quadrant of the MICMAC analysis is the dependent quadrant. As the name suggests, the barriers in the dependent

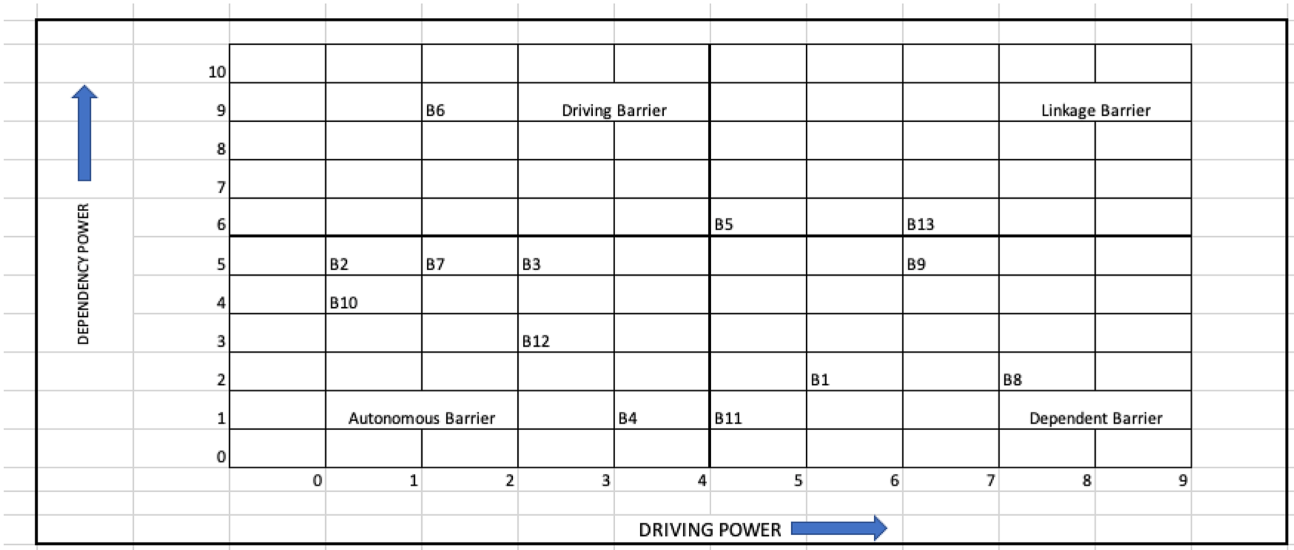

Fig. 5 Graph showing relationship between driving and dependence power

Table 7 Levels partition of barriers

Barrier	Reachability set	Antecedent set	Inter-section set	Level
B1	1,2,5,6,10,13	1,9,	1	5
B2	2	1,2,6,9,12	2	1
B3	3,6,7	3,4,7,8,13	3,7	3
B4	3,4,7,13	4	4	5
B5	5,6,7,8,13	1,5,8,9,11,13	5,8,13	3
B6	2,6	1,3,5,6,8,9,11,12,13	6	2
B7	3,7	3,4,7,8,13	3,7	1
B8	3,5,6,7,8,9,10,13	5,8	5,8	7
B9	1,2,5,6,9,10,13	5,8,9,11,13	5,9,13	6
B10	10	1,8,9,10	10	1
B11	5,6,9,11,12	11	11	7
B12	2,6,12	11,12,13	12	3
B13	3,5,6,7,912,13	1,4,5,8,9,13	13	4

quadrant depend on other barriers and have low driving power. Lack of knowledge (B1) comes into this category which tells that this is not the main reason for not adopting digital technologies in Industry 4.0 but the barrier indirectly affects the system and the magnitude is dependent on other variables. From previous studies, it is evident that proper understanding of technology along with agreeing to other supply chain partners/organizations would pave way for the smooth execution of implementation of Industry 4.0.

The third quadrant of the TISM model is known as the linkage quadrant. This quadrant consists of linkage variables. These variables give balance to the system and also make the system secure. Any changes to these variables would disturb the balance of the system. Security challenge(B5), dependent on third party technology(B13) come in the third quadrant. They come in the category of linkage variables. These barriers which are in the linkage variables category form an important part of the system since they bring stability to the system. They have high power which keeps the structure in balance. These variables also can disturb the balance of the system if they are not treated properly given that they have high influence and dependence on other variables.

The fourth quadrant of the TISM model is known as the driving quadrant. The elements in this quadrant are most influential in the adoption of digital technologies in Industry 4.0. Negative perception towards technology(B6) comes in the fourth quadrant. This quadrant has the most driving power compared to other quadrants which makes it the most influential quadrant. It has less dependence power, i.e., it is not much dependent on other barriers in the system. Hence, the elements in this quadrant would be the main cause of disturbance in the system and therefore has to be given at most priority.

4 Implications

4.1 Theoretical implications

This research adds to the current theoretical information in areas of digital technologies and barriers in implementing it in Industry 4.0. The study is the first to describe and analyze the barriers which hinder the implementation of Industry 4.0. Second, utilizing a TISM-MICMAC-based strategy, this study develops contextual links between identified business logistical management constraints. None of the available papers have yet studied the interdependency between supply chain barriers. To better understand the nature of the detected barriers, researchers can utilize the MICMAC technique to classify the barriers.

The driving force and dependence of each barrier were calculated in our study. It is based on literature and data reviews from various experts, who have categorized the barriers into four coordinates constituted by MICMAC. Our research helps researchers better recognize the behavioral relationship between the barriers by splitting the barrier levels of the proposed TISM model and their connections across multiple layers. In this way, by incorporating our unique TISM and MICMAC methods, our research has grown significantly and has provided researchers with a sense of connection that transcends barriers and levels. Future scholars hope to be able to empirically test hypotheses among the key variables obtained in the TISM model.

4.2 Managerial implications

The study gives relevant information to the senior members of an organization in the implementation of Industry 4.0. It would also help to modernize or change the trends in the supply chain. The study also provides the managers with the barriers which hinder the adoption of digital technologies in Industry 4.0. The research particularly conveys the two most important barriers which hinder the approach. The study shows that unclear government policy and lack of knowledge and expertise could be the most dominant barriers in the implementation of Industry 4.0 (Bui et al. 2022). The managers should focus more on these barriers and try to eliminate them on a priority basis. Some of the ways it could be done are by creating awareness on digital technologies and supply chain among professionals so that they could understand how the technologies would benefit them in the future. This would also make the organizations to be in a better position to adopt digital technologies and they could equip themselves with the latest technology (Sohal et al., 2022).

If the managers follow the above method to eliminate the barriers, there would be healthy participation and a combined effort from the professionals which would make the adoption process lot easier. Another key barrier is the immaturity of technology or the inability of organizations to equip themselves with the latest technologies (Jhariya et al. 2022). One of the solutions to eliminate this barrier is by creating awareness among individuals on the latest technologies. The managers must have communication with business owners to convince them to use the latest technologies. This would help to create more awareness and would make the adoption process easier (Biswal et al. 2019) The managers should take into account each of the barriers and assess the barriers one by one and try to eliminate the barriers.

5 Conclusion

For Companies to be competitive in the present time, right implementation of Industry 4.0, digitization has been proven to be a critical factor. Proper Industry 4.0 technologies with a Circular Economy will pave way for sustainable operations. There are various barriers that industries are facing which obstruct Industry 4.0 and Circular Economy and the challenge would be to integrate these new technologies with the current systems in an integrated and effective manner. TISM gives a transitive linkage between all the barriers and considers the dynamic relations and linkages between the barriers and establishes a model portraying all the barriers to adoption of Industry 4.0 technologies. Further, the research work recognizes barriers that are to be addressed and removed for the effective adoption of Industry 4.0 technology in supply chains. Lack of knowledge with Industry 4.0 technology, immaturity of technology for the future supply chain is the most influential barriers that have been identified by the model using TISM. These barriers are very critical for establishing Industry 4.0 and other barriers behave as a correlation as established by the MICMAC analysis in the supply chain.

The research is about the barriers to the adoption of digital technologies in Industry 4.0.

Investing is very important when it comes to deploying the latest technology Challenges in different industries, but in the long run the organization can become more consistent. Further, various policies from the government can strengthen sustainable practise and help in promoting digitalization for driving a circular economy that meets the demands of Industry 4.0. Although the study discusses about various barriers in terms of adoption, it does not address the barriers in terms of implementation. Along with the adoption of technologies, the focus has to be given to people who could enable the adoption so that it could be implemented. The adoption managers can focus on eliminating the barriers to the successful implementation of digital technologies. Once the barriers are eliminated, the technologies could be implemented in Industry 4.0. According to Pareto's Law, 80% of effects are due to 20% causes.

This research work minimizes the lack of thought revolving around Industry 4.0 as we used TISM for analysing interactions within the barriers and MICMAC analysis for recognizing influential barriers. This paper has provided to the supply chain literature by addressing Industry 4.0 innovations. This paper examines TISM's ability to investigate the reasons for transitive connections. This will give you more insights into the system and validate the TISM model developed for thirteen barriers for the implementation of Industry 4.0 in the supply chain. This paper contributes to the current literature on Industry 4.0 technology in supply chain management. Acceptance of new technology-focused on adopted enablers Important and adoption managers can work on tasks to remove obstacles for successful implementation of Industry 4.0 technology throughout the supply chain. The final output says that the companies/expertise interviewed are well aware of the necessity for them to move ahead towards more sustainable operations involving more CE concepts.

The barriers identified are investigated and the results could guide companies in their efforts to move their business models to reuse, remanufacture and recycle. The limitations and the prospects for future research have also been mentioned.

Although our study developed a model using TISM and identified the barriers to the adoption of digital technologies in Industry 4.0, it lacked quantitative analysis. The impact of the barriers was subjectively analyzed but there was not much quantitative analysis. One of the processes which can be used for validating the model is Structural Equation Modeling (SEM) and the analytic network process. Another way to improve is by using grey and fuzzy theories. One of the drawbacks of the study was that it had limited responses. By using grey and fuzzy theories, the drawback of a limited number of responses can be improved by considering the fuzziness of the respondents. The preference and experience of the respondents can be included by using MICMAC analysis based on grey weights. Another method to identify the important barriers is by using Decision Making Trial and Evaluation Laboratory (DEMATEL). The mutual dominance effect of the barriers can be quantified by using a hybrid method known as D-ANP (DEMATEL based Analytic Network Process). The study has not used a questionnaire to test the model. In the future, we can use confirmatory analysis to test the developed model.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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