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Examining the facilitators of I4.0 practices to attain stakeholders' collaboration: a circular perspective

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ABSTRACT
The fourth industrial revolution (I4.0) has changed the traditional business model, bringing various benefits, including increased efficiency and productivity in organizations. However, to attain success in I4.0 practices requires collaboration from various stakeholders. This study objectives to identify the facilitators of I4.0 practices that can lead to successful collaboration among stakeholders from a circular perspective. An extensive literature review is performed to identify 14 potential facilitators. Further, the study adopts a mixed methodology of Best-Worst Method (BWM) and Interpretive Structural Modeling (ISM) to analyze the interconnectedness among the identified facilitators. BWM method was used to determine the relative importance of the identified facilitators, while ISM technique was used to determine the relationships between the facilitators of I4.0 practices. The findings from the study reveal that to strengthen stakeholder collaboration, organizations need to focus more on training and capacity-building programs and create more opportunities for technology exchange.

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Industry 4.0; stakeholder collaboration; facilitators; circular economy

1. Introduction

The Fourth Industrial Revolution (I4.0) has brought significant changes in manufacturing practices by integrating digital technologies with physical systems (Hettiarachchi et al., 2022). This integration has led to the creation of smart factories, supply chains, and products. I4.0 technology has the potential to enable Circular Economy (CE) by creating more efficient and sustainable adoption of resources. In recent years, circularity has gained traction as a means of achieving sustainability in manufacturing (EMF, 2015). Circularity is based on the principles of the CE, which aims to eliminate waste and promote the reuse of resources

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(Genovese et al., 2017). Circular practices can be applied to I4.0 to promote collaboration among stakeholders (Massaro et al., 2021; Pfaff, 2023). The circular perspective recognizes that stakeholders are interdependent and interconnected and their actions can have an impact on each other and on the environment. Also, circular practices enable stakeholders to work together to optimize the use of resources, reduce waste, and promote sustainable outcomes (Lardo et al., 2020; Dwivedi et al., 2023).

By creating closed-loop systems, enabling collaboration and sharing, using predictive maintenance techniques, 3D printing technologies, and creating digital marketplaces, I4.0 can help reduce waste, optimize the use of resources, and promote sustainability (Bhatia & Kumar, 2022; Veile et al., 2020). However, realizing the potential of I4.0 in enabling CE requires a cultural shift that fosters collaboration and a holistic approach and recognizes the interdependence of stakeholders. Collaboration involves the exchange of information, knowledge, and expertise among stakeholders to achieve common objectives. Collaboration enables stakeholders to learn from each other, identify opportunities for improvement, and create new products and services that cater the requirement of customers (Barrane et al., 2021). It is important for organizations to recognize the potential benefits of I4.0 technologies and to adopt these technologies in a way that promotes CE and a more sustainable future (Rosa et al., 2020).

Despite the growing interest in I4.0 practices and the importance of stakeholder collaboration, there remains a notable research gap in understanding how a circular perspective can specifically facilitate and enhance stakeholders' collaboration in the context of I4.0 adoption. While some studies have explored stakeholder engagement in I4.0 implementation, limited attention has been given to the CEs contribution as a facilitator for promoting collaborative efforts among stakeholders (Barrane et al., 2021; Fobbe & Hilletofth, 2023). Thus, there is a requirement for research that delves deeper into the potential benefits and challenges of adopting a circular perspective in the context of I4.0 practices to foster stakeholders' collaboration and achieve sustainable outcomes. Addressing this research gap will provide valuable insights into the synergistic effects of circular thinking and stakeholder engagement, shedding light on effective strategies for promoting sustainable and inclusive I4.0 initiatives that benefit all involved stakeholders. Thus, in order to address these issues following Research Questions (RQs) have been outlined:

RQ1: What are the facilitators of I4.0 practices to attain stakeholders' collaboration in a CE?

RQ2: How can the inter-relationships among I4.0 practices be analyzed?

RQ3: How can the driving-dependence impact of each facilitator of I4.0 practices be obtained?

Based on RQs, following Research Objectives (ROs) are framed:

RO1: To identify the potential facilitators that promote stakeholder collaboration in implementing I4.0 practices;

RO2: To evaluate their impact and explore their interdependencies.

To fulfill the ROs, the study uses the theoretical lens of stakeholder's theory (Crane & Ruebottom, 2011). By applying stakeholder theory from a circular perspective, organizations can enhance collaboration, build sustainable practices, and create positive impacts for all stakeholders involved in the implementation of I4.0 practices. The significance of incorporating stakeholder theory into an organization's practices and supply chain has been acknowledged by various researchers (Baah et al., 2022; Shah & Bookbinder, 2022) as it enhances the overall conceptual understanding of implementation. Nevertheless, existing research on CE has predominantly focused on resource-based and institutional theory perspectives, leaving the relationship between CE and stakeholder theory relatively unexplored (De Angelis, 2021; Lahane et al., 2020). The major objective of this study is to contribute towards literature by evaluating the contributions of collaboration among stakeholders related to I4.0 practices to attain circularity. By identifying the facilitators of I4.0 practices that promote stakeholders' collaboration towards circularity, this study seeks to provide insights to help organizations adopt I4.0 practices more effectively and to foster a more sustainable future. While research on I4.0 and CE has advanced in recent years, there are still several research gaps that need to be explored in terms of facilitators of I4.0 practices for achieving stakeholder collaboration for CE. Although there is plethora of literature on establishing the connect between circularity and I4.0 (Dalenogare et al., 2018; Dwivedi et al., 2023). Still, the domain of stakeholder collaboration in relation with I4.0 practices is in a very nascent stage.

To identify the facilitators of I4.0 practices to attain stakeholders' collaboration, a thorough examination of existing literature and expert opinions is performed. The significance of each facilitator is determined by utilizing Best-Worst Method (BWM) to calculate their weight. Additionally, since these facilitators are not operating in isolation but rather influencing each other, Interpretive Structural Modelling (ISM) with Cross-Impact Matrix Multiplication Applied To Classification (MICMAC) is applied to assess their interrelationships. It is expected that utilizing a comprehensive decision-making approach will aid decision-makers in thoroughly evaluating the factors that enable the adoption of I4.0 practices and achieving cooperation from stakeholders. This assistance may have significant implications for the sustainable growth and implementation of circular principles.

The remaining part of the study is divided into several sections: Section 2 explains the facilitators that support the implementation of I4.0 practices to foster stakeholder collaboration. Section 3 details the research methodology used in this study. Section 4 presents the study's results. Section 5 discusses the practical implications of the study for managers, and finally, Section 6 provides concluding remarks for the study.

2. Literature review

In this study, a comprehensive search in the SCOPUS, Web of Science (WoS) database covering the period of last decade (from April 2013 to April 2023) as we have witnessed a remarkable emergence of the I4.0 and the growing significance of CE in the mentioned time-period (Awan et al., 2021; Patyal et al. 2022). The search utilized various keyword combinations related to CE, circularity, Circular Business Models (CBMs), I4.0, I4.0 stakeholder, facilitators, drivers etc. The conference papers and reports were excluded from the search. Due to the prevalence of articles in business, management, accounting, social sciences, decision sciences, and engineering, we focused our search exclusively on these subject areas. This section is segregated into three parts. The first part highlights the studies related to I4.0, CE and stakeholders collaboration. The facilitators of I4.0 practices for stakeholder collaboration are highlighted in part second. The research gaps are presented in part three.

2.1. Stakeholder theory and CE

Stakeholder collaboration is a fundamental concept in stakeholder theory (Freeman et al., 2017) and is widely utilized in circularity and business research. This theory asserts that for organizations to ensure their survival, they must consider stakeholders in their value-generation processes (Chang et al., 2017; H€orisch et al., 2014). Stakeholders, in this context, encompass individuals, groups, or organizations that are impacted by or have an impact on organizational activities (Freeman, 1984). Stakeholders are typically classified as internal (employees and management) and external (suppliers, customers, government, and NGOs) (Bryson, 2004). Stakeholder collaboration, within the purview of stakeholder theory, refers to the active and cooperative engagement of individuals, groups, or organizations that have a vested interest or are affected by an organization's activities, decisions, or outcomes. In stakeholder theory, organizations are viewed as having a responsibility not only towards their shareholders but also towards other stakeholders, such as employees, customers, suppliers, local communities, regulators, and Non-Governmental Organizations (NGOs) (Crane & Ruebottom, 2011). This collaborative approach aims to foster mutually beneficial outcomes, shared value creation, and the achievement of common goals (Chang et al., 2017). Stakeholder collaboration exerts a profound influence on CE, propelling the transition towards a more sustainable and resource-efficient economic model (H€orisch et al., 2014). Businesses collaborate with suppliers and customers to design products with extended lifespans, implement closed-loop systems, and explore new business models that prioritize resource conservation and waste reduction (Moktadir et al., 2021). Additionally, stakeholders advocate for supportive policies and regulations that incentivize circular practices, removing barriers and creating an enabling environment for circular initiatives to flourish. This collective push for policy changes contributes to the scaling and mainstreaming of circular practices across industries and supply chains (Shah & Bookbinder, 2022). Through stakeholder collaboration, a shared vision and common goals for CE are established, aligning interests and aspirations to collectively work towards a more sustainable future (Freeman et al., 2017). In the context of I4.0, stakeholder collaboration assumes even greater significance as it influences the CEs integration and impact on modern manufacturing processes. I4.0, characterized by the digitalization and automation, offers new opportunities for circular practices through smart and connected technologies (De Angelis, 2021). Stakeholder collaboration becomes essential in this scenario as businesses, technology providers, policymakers, and consumers must work together to harness the potential of I4.0 for circularity (Patil et al., 2023). Collaborative efforts enable the co-design and implementation of innovative circular business models, such as product-as-a-service and remanufacturing, which leverage real-time data and analytics to optimize resource usage and minimize waste throughout the product lifecycle (Baah et al., 2022).

Through stakeholder collaboration, I4.0 can enable better information sharing and transparency, allowing all stakeholders to access and analyze relevant data related to product design, production, usage, and end-of-life management. This increased data transparency promotes more informed decision-making, facilitates CSC management, and fosters a circular ecosystem where stakeholders actively participate in sustainable practices (H€orisch et al., 2014; De Angelis, 2021). Additionally, collaborative initiatives can address potential challenges in the adoption of I4.0 technologies for circularity, such as ensuring inclusivity, considering social impacts, and addressing privacy and security concerns. By working together, stakeholders can co-create solutions that maximize the CEs potential in the I4.0 era, leading to a more resilient, resource-efficient, and sustainable manufacturing landscape.

2.2. Studies specific to industry 4.0(I4.0), circular economy (CE) and stakeholders collaboration

Zheng et al. (2023) analyzes how I4.0 enables Small and Medium Enterprises (SMEs) in emerging economies to establish and sustain organizational legitimacy with the public and to benefit from the adoption of the circular economy (CE) in their organizations. The findings reflect that I4.0 could assist SMEs to advance organizational legitimacy. Also, Ijaz Baig and Yadegaridehkordi (2023) moderated the effects of I4.0 employment on businesses' sustainability. The employment of I4.0 demonstrated notable moderating impacts on sustainable performance's financial and environmental facets. A study to examine the inter-relations among I4.0 and digital entrepreneurship was highlighted (Mondal et al., 2023). The findings reflect that Digital Twin (DT) is achieved by I4.0 practices in the manufacturing domain. Further, Bag et al. (2023) adopts stakeholder theory to offer a more sophisticated view of virtue ethics' implications for big data. A study to concentrate on analyzing the existing condition of furniture companies based on I4.0 advantages was suggested (Červený et al., 2022). The findings from study reflect that production and non-production technologies are beneficial for businesses.

Kayikci et al. (2022) identified the drivers of a smart sustainable circular supply chain (SSCSC) adopting the stakeholder theory. The findings of the study identifies drivers and analyzes them by implementation of BWM analysis. A study to arrest the suggestions of stakeholders regarding different dimensions of Lean Six Sigma (LSS) was presented (Yadav & Al Owad, 2022). Similarly, Niehoff (2022) analyzes the connections among corporate digitalisation and sustainability management. The results from the study reflect business-centered sustainability on digitalisation. A study to evaluate whether competitive pressures towards sustainability motivate organizations towards I4.0 adoption (Bhatia & Kumar, 2022). The findings from the study reflect that environmental commitment resolves the effect competitive pressures on I4.0 adoption. Further, Sony et al. (2022) adopted an exploratory sequential mixed method to analyze the Critical

Failure Factors (CFFs) for I4.0. A bibliometric analysis is provided to highlight the studies relevant to sustainable manufacturing and I4.0 under the aegis of sustainable manufacturing 4.0 (Gholami et al., 2021).

Shet and Pereira (2021) proposed the managerial implications required for a successful I4.0 atmosphere. Ghobakhloo (2020) developed a pathway for businesses to take advantage from I4.0 adoption to attain sustainability. I4.0 practices and digital technology assist businesses to efficiently collaborate with internal and external stakeholders. Additionally, Ciliberto et al. (2021) explored the integration of sustainable and lean production and how I4.0 practices can provide a platform for CE initiatives. Dikhanbayeva et al. (2021) conducted a study to identify the critical factors for the adoption of Industry 4.0 practices in Kazakhstan and their implications for future implementation of these practices. Awan et al. (2021) investigated the expectations of stakeholders towards the Internet of Things (IoT) and its potential role in CE management. The study's findings offer insights to both practitioners and researchers on the essential components of the transition towards a CE. Furthermore, Massaro et al. (2021) examined the relationship between I4.0 and CE, aiming to understand how I4.0 can enhance the impact of CE practices on organizations. Table 1 provides an overview of potential studies that focus on I4.0, CE, and stakeholder collaboration.

2.3. Identification of facilitators of I4.0 practices for stakeholder collaboration

In the context of I4.0 practices, effective stakeholder collaboration is crucial for achieving success. Stakeholders include suppliers, customers, partners, and employees, among others. To collaborate effectively, stakeholders need to share information, knowledge, and resources in a timely and efficient manner. Facilitators of I4.0 practices for stakeholder collaboration are the critical success factors or drivers that enable this collaboration to take place. The objective of identified facilitators is to foster collaboration, innovation, and agility among stakeholders, resulting in improved decision-making, faster time-to-market, and enhanced customer satisfaction. Using an extensive literature review approach, this study identified 14 potential facilitators of I4.0 practices for stakeholder collaboration. Table 2 elucidates upon the identified facilitators of I4.0 practices for stakeholder collaboration.

2.4. Research gaps

The past literature establish that vesting a cultural shift in terms of strengthening stakeholders' collaboration through advanced technologies result in more empowered environment holistically. To understand and integrate the I4.0 practices for empowering stakeholder's collaboration, it is important to assess and analyze the facilitators of I4.0 practices to attain stakeholders' collaboration (Varela et al., 2023). However, there are studies that identified the drivers or success factors for implementing I4.0 but specifically in terms of stakeholders' collaboration there is a dearth of literature. This clearly presents a research gap. Hence, the aim of this study is to bridge the gap in the current literature by utilizing a decision analysis approach. The research has two primary objectives: firstly, to identify the key facilitators that promote stakeholder collaboration in implementing I4.0 practices, and secondly, to evaluate the degree of their impact and explore their interdependencies.

Table 1. Potential studies related to I4.0, CE and stakeholders collaboration.

Objective	Methodology	Outcome	Source
This study analyzes how I4.0 enables SMEs in developing markets to benefit from the adoption of the CE.	Case study approach	The findings reflect that two mechanisms could be utilized to encourage SMEs to enhance their organizational legitimacy for implementing I4.0.	Zheng et al. (2023)
In this study, the moderating effects of I4.0 adoption on different pillars of sustainability are explored.	Structural Equation Modeling (SEM)	Adoption of I4.0 demonstrated notable moderating impacts on sustainable performance's financial and environmental facets.	Ijaz Baig and Yadegaridehkordi (2023)
This study examines the interaction among I4.0 and digital entrepreneurship.	Structural Equation Modeling (SEM)	Digital Twin is achieved by I4.0 in the manufacturing domain.	Mondal et al. (2023)
This study concentrates on analyzing the furniture organizations related to I4.0 benefits/threats.	Qualitative Content Analysis (QCA)	Innovative production and non-production technology in the opinion of the stakeholders, are important for their businesses.	Červený et al. (2022)
The purpose of this study is to identify drivers of a smart sustainable circular supply chain (SSCSC).	Best-Worst Method (BWM) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).	The results from the study identifies drivers and analyzes them by implementation of BWM.	Kayikci et al. (2022)
This study arrests the suggestions of stakeholders regarding various dimensions of Lean Six Sigma (LSS).	Empirical research and Analysis of Variance (ANOVA) variance) methods.	The study evaluates the statistically significant difference between various stakeholders' views.	Yadav and Al Owad (2022)
This study discusses the potential of blockchain to deliver business values.	Systematic Literature Review (SLR)	The study provides a platform to share manufacturing information.	Ali et al. (2022)
This study analyzes the connections among corporate digitalization and sustainability.	Statisitical Analysis	The results reflect a view of business-centered sustainability on digitalization.	Niehoff (2022)
In this study, I4.0 technologies integrated with Corporate Social Responsibility (CSR) are analyzed as CSR 4.0 practices.	DEMATEL approach	The results reflect that influential practices are corelated with CSR 4.0 performances.	Govindan and Hasanagic (2018)
This study proposes the managerial implications necessary for a successful I4.0 atmosphere.	Literature Review	This study benefit everyone to engage in developing the capabilities necessary for an I4.0 paradigm.	Shet and Pereira (2021)
This study efforts to design a synergy among sustainable and lean production.	Conceptual framework	This study summarizes the production principles for a competitive and sustainable business.	Ciliberto et al. (2021)
This study efforts to analyse the critical factors for implementation of I4.0 practices in Kazakhstan	Primary and secondary data sources	The results from the study develop forecasts implementation processes of I4.0.	Dikhanbayeva et al. (2021)
This study examines the different factors that influence the progression of I4.0 for sustainable education.	SWOT and Analytic Hierarchy process (AHP)	The results reflect that there is effective financial planning for universities in I4.0.	Mian et al. (2020)
This study objectives to analyze the impact of I4.0 on environmental sustainability.	Literature Review	The findings reflect that there is a negative interaction related to the production process flow from the inputs to the final product.	Oláh et al. (2020)

Table 2. Facilitators of I4.0 practices for stakeholder collaboration.

S. No.	Facilitators of I4.0 practices for stakeholder collaboration	Description	References
FA1	Embracing a shared vision philosophy	Stakeholders need to have a common understanding of Circular Economy (CE) and a shared vision of desired outcomes.	Galati and Bigliardi (2019); Rahman et al., (2020)
FA2	Facilitating communication and mutual respect	Effective communication channels and mechanisms should be established to facilitate regular and transparent communication among stakeholders. Building trust and fostering mutual respect among stakeholders is essential for successful collaboration in attaining CE objectives.	Bosman et al. (2020); Peiro-Signes et al., (2022)
FA3	Provisions for resource sharing	Collective sharing of resources, such as knowledge, expertise, and infrastructure, can accelerate the transition to CE perspective.	Govindan and Hasanagic (2018); Peiro-Signes et al., (2022)
FA4	Advocating circular lifecycle thinking approach	Advocating CE principles and policies can develop an enabling environment for stakeholder collaboration and CE implementation. The stakeholders need to adopt a life cycle thinking approach throughout the life cycle.	Machado et al. (2020); Yadav et al. (2020)
FA5	Opportunities for collaborative technology exchange	Embracing advanced technologies and innovation, such as digitalization, automation, and data analytics, can enable more effective and efficient CE practices. The collaboration among circular innovation and research and development (R&D) activities, such as developing new technologies, materials, and business models, can foster stakeholder collaboration and drive CE innovation.	Blunck and Werthmann (2017); Govindan and Hasanagic (2018)
FA6	Emphasizing circular business networks and partnerships	Building digital networks and partnerships among stakeholders, such as industry associations, research institutions, and government agencies, can foster knowledge sharing, innovation, and collaboration in CE initiatives.	Anbumozhi et al. (2020); Yadav et al. (2020)
FA7	Promoting standardization and interoperability	Promoting standardization and interoperability of I4.0 technologies and practices among stakeholders can enhance collaboration in implementing CE initiatives.	Pham et al. (2019); Dranka and Ferreira (2020)
FA8	Providing training and capacity building programs	Providing training and capacity-building programs to stakeholders enhances their skills and knowledge towards I4.0 practices. Further, CE principles can foster collaboration and adoption of advanced technologies.	Bonilla et al. (2018); Galati and Bigliardi (2019)
FA9	Adopting an agile and flexible culture towards circularity	Adopting an agile and flexible mindset towards CE and I4.0 practices can foster collaboration by enabling stakeholders to adapt towards changing circumstances.	Rajput and Singh (2019); Anbumozhi et al. (2020)
FA10	Ensuring technological readiness	Ensuring stakeholders have the necessary technological capabilities and infrastructure to implement I4.0 practices can facilitate collaboration in adopting advanced technologies for CE initiatives.	Lin et al. (2019); Ivanov and Dolgui (2021)
FA11	Maintaining value chain collaboration	Collaboration across the entire value chain, from raw material extraction to product disposal, is crucial for successful implementation of CE concept.	Rajput and Singh (2019); Jonak et al. (2020)

(*Continued*)

Table 2. (Continued).

S. No.	Facilitators of I4.0 practices for stakeholder collaboration	Description	References
FA12	Ensuring transparency through circular supply chain visibility	Implementing Digital Supply Chain (DSC) visibility solutions that provide real-time tracking and monitoring of products, materials, and waste along the supply chain can enhance stakeholder collaboration and coordination.	Antikainen et al. (2018); Mastos et al. (2021)
FA13	Enabling decentralized decision making	I4.0 technologies can enable stakeholders to make decentralized and autonomous decisions based on real-time data and analytics, facilitating collaboration and empowerment among stakeholders in CE initiatives.	Dahlgaard et al. (2013); Ghobakhloo (2020); Anbumozhi et al. (2020)
FA14	Fostering a culture of continuous improvement	Encouraging a culture of continuous improvement among stakeholders by regularly reviewing and refining CE and I4.0 practices can foster collaboration in driving ongoing progress.	Lidenhammar (2015); Rajput and Singh (2019);

3. Methodology

Facilitators of I4.0 practices for stakeholder collaboration were identified from literature review and the expert opinion. Later, Best Worst method (BWM) is employed to rank the identified potential facilitators. BWM helps in identifying the important factors among available. Next, the interrelationship between the facilitators was obtained using Interpretive Structure Modeling (ISM) and MICMAC analysis. The ISM method gives the directional relationship between facilitators, and MICMAC categorizes them into 4 clusters which suggest their importance in overall system. The output form these analysis presents a framework which can be helpful for development of strategies and policies to utilize the I4.0 practices for stakeholder collaboration.

3.1. Best-worst method (BWM)

Best-Worst is a Multi-Criteria Decision-Making (MCDM) method which was originally developed by Rezaei in 2015 (Rezaei, 2015). It employs a pairwise comparison approach that involves the use of two reference points, namely 'best' and 'worst,' to compare other criteria. Various researchers have utilized this method for different purposes. Khan et al. (2023) applied it to analyze the barriers of food supply chain which is integrated with blockchain. Rezaei et al. (2018) used it in airline industry for the quality evaluation of their baggage handling. Gupta and Barua (2017) used BWM in combination with fuzzy TOPSIS for the supplier selection problem focusing on their ability for green innovation. Similarly, BWM has been used in many other industries and problem domain such as assessment of new technology, e-waste management, energy security etc (Rezaei, 2020). Nevertheless, this particular study is the first to implement the BWM method for examining the Facilitators of I4.0 practices for stakeholder collaboration. The step by step process for application of BWM methodology can be found at Rezaei (2015).

3.2. Interpretive structure modeling (ISM)

Interpretive Structural Modeling (ISM) is an interactive approach given by Warfield (1974). It is used to structure complex issues into a systematic model that maps out the relationships among various variables. When dealing with complex problems, there are often several factors that are related to the issue or problem at hand. However, it is the direct and indirect relationships between these factors that provide a more accurate description of the situation than considering each factor in isolation (Liang et al., 2022). This technique is particularly useful in gaining collective insights into these relationships, which can enhance our understanding of complex problems. This methodology is considered suitable for application in multiple fields due to its ability to provide structured and efficient insight into any given issue (Raut et al., 2017). Researchers have used ISM in supply chain management, reverse logistics, supplier selection, green lean implementation, shipping policy, and sustainable business, among other fields (Anam et al., 2022; Kumar & Goel, 2022). The procedural steps of the ISM methodology can be found from Attri et al. (2013).

3.3. MICMAC analysis

To assess the driving power and dependence power of different factors, a MICMAC analysis is used. This analysis employs the multiplication properties of matrices and helps to identify the key drivers in various categories. Based on their level of driving power and dependence power, the factors are then classified into four categories – autonomous factors, linkage factors, dependent factors, and independent factors. This categorization aids in comprehending the role of each factor in either driving or being dependent on the system. Anam et al. (2022) adopted this approach to gain a better understanding of the factors and their respective roles in the system.

3.4. Data collection and analysis

Data collection was performed with the help of 11 experts from different manufacturing industry and academicians in Northern region in India (Appendix F). Initially, the experts were appraised regarding the facilitators and they were requested to select the best and worst facilitators. Later they have to compare the best and worst facilitators with other facilitators using the 1–9 scale as required by BWM method. After data collection, the procedure of BWM method were followed to find out the optimal weights of each facilitators. Subsequently, the consistency ratio of the pairwise comparisons was assessed and compared against the input threshold values from Liang et al. (2020). It was observed that all the obtained weights were lower than their corresponding threshold values, indicating their reliability. The final rankings of the facilitators were determined by computing the average weights provided by each expert through the BWM methodology, as illustrated in Table 3. Next, on the basis of the optimal weights and discussion with the experts, two of the facilitators with lowest weights, i.e. The facilitator (FA1) and (FA3) were removed and remaining 12 facilitators were considered for ISM and MICMAC analysis.

Table 3. Optimal weights using BWM method.

Code	Facilitators	Weight	Rank
FA1	Embracing a shared vision philosophy	0.013258	13
FA2	Facilitating communication and mutual respect	0.05303	7
FA3	Provisions for resource sharing	0.008671	14
FA4	Advocating circular lifecycle thinking approach	0.05303	6
FA5	Opportunities for collaborative technology exchange	0.13872	2
FA6	Emphasizing circular business networks and partnerships	0.093931	4
FA7	Promoting standardization and interoperability	0.06936	5
FA8	Providing training and capacity building programs	0.257622	1
FA9	Adopting an agile and flexible culture towards circularity	0.132576	3
FA10	Ensuring technological readiness	0.04624	8
FA11	Maintaining value chain collaboration	0.029726	11
FA12	Ensuring transparency through circular supply chain visibility	0.027457	12
FA13	Enabling decentralized decision making	0.036609	10
FA14	Fostering a culture of continuous improvement	0.039773	9

Table 4. Driving and dependence power.

S. No.	FA2	FA4	FA5	FA6	FA7	FA8	FA9	FA10	FA11	FA12	FA13	FA14	Driving power
FA2	1	1	1*	1*	1*	1	1*	1*	1*	1*	1*	1*	**12**
FA4	1	1	1*	1*	1*	1	1*	1*	1*	1*	1*	1*	**12**
FA5	1*	0	1	1*	1	0	1	1	0	0	1*	1	**8**
FA6	0	0	1	1	1*	0	1*	1*	0	0	0	1*	**6**
FA7	1*	0	1*	1	1	0	1	1*	0	0	0	1	**7**
FA8	1*	1*	1	1	1	1	1	1	1	1	1	1	**12**
FA9	1	1*	0	0	0	1*	1	1	0	0	1*	1*	**7**
FA10	0	1*	1*	0	0	0	1*	1	1	0	1	1	**6**
FA11	1	1*	1*	0	0	1*	1*	1	1	0	1	1*	**9**
FA12	1*	0	1*	1	0	0	0	1*	1	1	1*	0	**7**
FA13	1*	1	1	0	1*	1*	1	1*	0	0	1	1*	**9**
FA14	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Dependence power	**9**	**7**	**10**	**7**	**7**	**6**	**10**	**11**	**5**	**4**	**9**	**11**	

3.4.1. ISM model

The experts were asked to provide data using scale as used in ISM method to prepare Structural Self-Interaction Matrix (SSIM) as shown in Appendix A. The SSIM was converted into Initial Reachability Matrix (IRM) using 0,1 scale as shown in Appendix B. Then the transitivity check performed to obtain final Reachability Matrix (FRM) as shown in Appendix C. Transitivity values are marked with *. Dependence power and driving power for each of facilitators were obtained by summing rows and column values in FRM respectively as shown in Table 4. Then the level partitioning was done to obtain levels for every facilitators. The reachability, antecedent and intersection set for each of the facilitators was obtained. Then iterations were performed to allocate levels to facilitators. A total of seven levels in seven iterations were obtained. Appendix D and Appendix E shows the Table for 1st iteration of level partitioning and consolidated Table of level portioning for all seven iterations respectively. The final ISM diagram was developed using information regarding levels and interrelationship of facilitators as shown in Figure 1.

3.4.2. MICMAC classification

After obtaining ISM diagram, the facilitators were classified on the basis of their driving and dependence power. Four clusters were formed as shown in Figure 2.

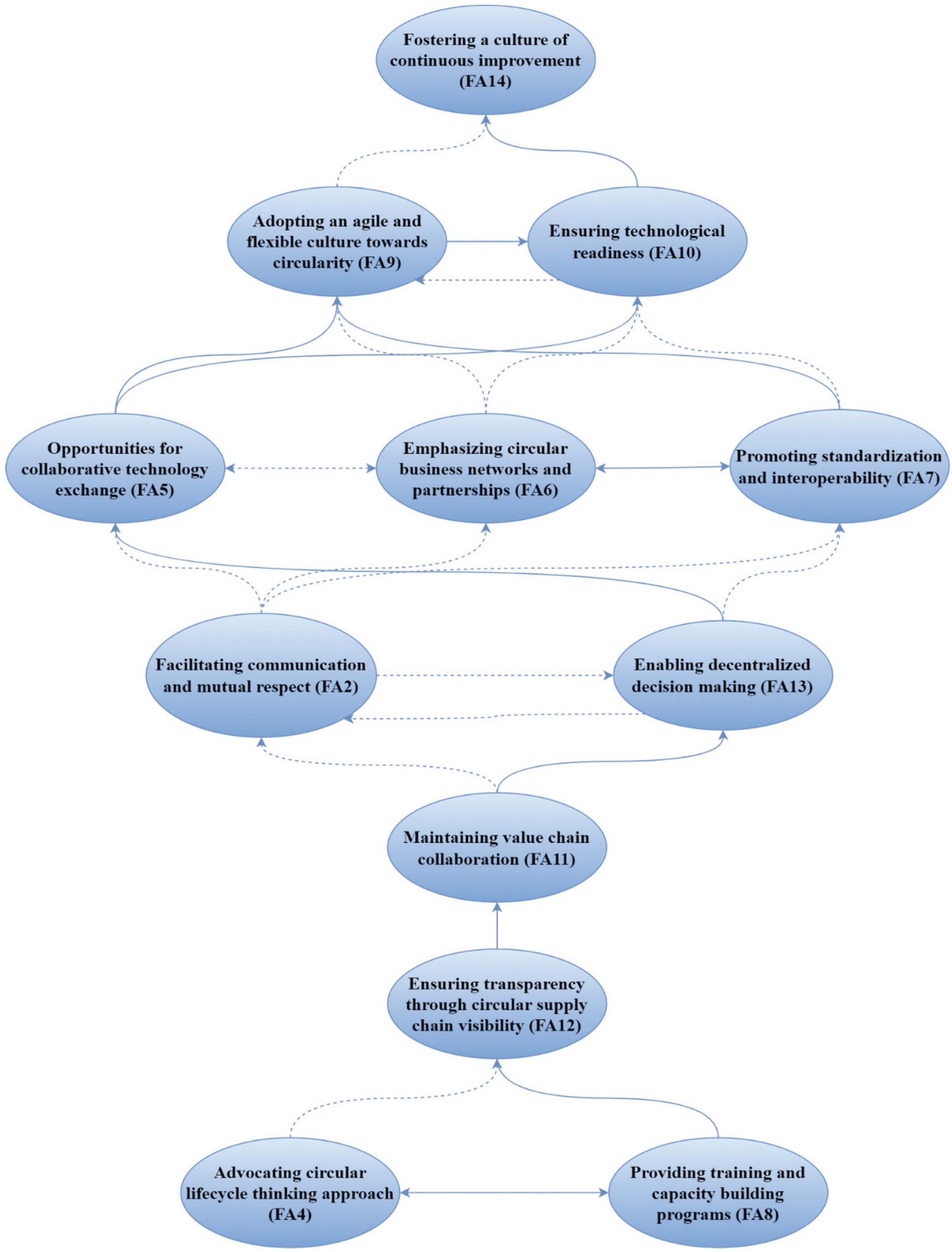

Figure 1. ISM diagraph.

4. Results and discussion

This study identifies the facilitators of I4.0 practices to attain stakeholder's collaboration. To achieve this, a rigorous mixed approach is adopted which includes a comprehensive review of literature and Multi Criteria Decision Making (MCDM) method. The study adopted an amalgamated approach of BWM and ISM-MICMAC method to establish interconnectedness between I4.0 practices and stakeholder's collaboration for maintaining a circular perspective.

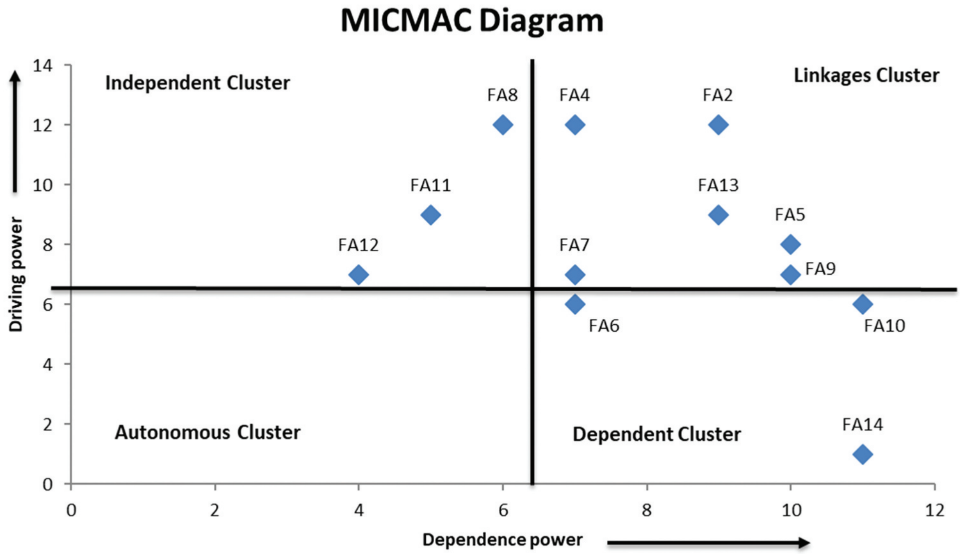

Figure 2. MICMAC classification.

The amalgamated approach combines the strengths of both BWM and ISM methods. BWM allows stakeholders to rank facilitators based on their perceived importance, while ISM establishes relationships between these facilitators. This combination can lead to a more comprehensive understanding of the factors influencing stakeholders' collaboration in the context of I4.0 practices. It offers practical implications for policymakers, organizations, and other stakeholders involved in the adoption of I4.0 practices. The results inform decision-making, resource allocation, and the design of collaborative initiatives in the context of Sustainable Development Goals (SDGs).

The utilization of BWM led to the finding of 'Providing training and capacity building programs (FA8)' as the most critical facilitator of I4.0 practices in achieving stakeholder collaboration. This facilitator received the highest weight and ranked first among all other facilitators. 'Opportunities for collaborative technology exchange (FA5)' and 'Adopting an agile and flexible culture towards circularity (FA9)' were identified as the second and third most significant facilitators, respectively. However, 'Ensuring transparency through circular supply chain visibility (FA12)', 'Embracing a shared vision philosophy (FA1)', and 'Provisions for resource sharing (FA3)', were ranked as the, twelfth, thirteenth, and fourteenth most important facilitators, respectively. It is worth noting that only the top 12 facilitators obtained from the BWM were used in developing the hierarchical structure using the ISM method (Fonseca et al., 2018).

To conduct ISM analysis, the levels were categorized based on the driving power and dependence power of the facilitators. ISM analysis results in seven levels as shown in Figure 1. Facilitator such as 'Fostering a culture of continuous improvement (FA14)' occupies the first level. Fostering a culture of continuous improvement can act as a catalyst for I4.0 by encouraging stakeholder collaboration. This is because a culture of continuous improvement promotes ongoing learning and development, which enables organizations to adapt to changing market conditions and stakeholder needs. By adopting this culture, organizations can create an environment that values innovation, efficiency, and collaboration, all of which are crucial to the success of I4.0. By involving stakeholders in the continuous improvement process, organizations can increase their engagement, satisfaction, and trust, which can lead to stronger collaboration and ultimately better outcomes for all parties involved. Therefore, fostering a culture of continuous improvement can be a critical facilitator for I4.0 in attaining stakeholder collaboration. On the other hand, 'Adopting an agile and flexible culture towards circularity (FA9)', 'Ensuring technological readiness (FA10)' and 'Facilitating communication and mutual respect (FA2)' occupies the second level in the dependence driver diagram. 'Adopting an agile and flexible culture towards circularity (FA9)' can enable organizations to respond quickly and effectively to change in stakeholder demands, preferences, and environmental factors. This promotes collaboration by allowing organizations to adapt their operations and products to meet stakeholder needs and expectations. Also ensuring 'technological readiness (FA10)' is crucial for I4.0 because it enables organizations to leverage advanced technologies to enhance their operations, products, and services. By investing in technology and ensuring it is up-to-date and effective, organizations can improve their efficiency and competitiveness, which can encourage stakeholder collaboration by offering greater value and convenience. Finally, facilitating communication and mutual respect is essential for promoting collaboration between stakeholders. By fostering open, transparent, and respectful communication channels, organizations can build trust among stakeholders. This can lead to greater cooperation and collaboration, as stakeholders feel valued, informed, and heard (Paulraj et al., 2008).

'Facilitators opportunities for collaborative technology exchange (FA5)', 'Emphasizing circular business networks and partnerships (FA6)', 'Promoting standardization and interoperability (FA7)', and provisions for resource sharing (FA3) occupies the third level in the ISM analysis. In CE, collaborative technology exchange can enable stakeholders to share knowledge, expertise, and resources, which can lead to collaboration and innovation in developing and implementing CE practices. By creating opportunities for technology exchange, organizations can build trust and relationships with stakeholders, which can lead to more effective collaboration in designing and implementing CE strategies. Also emphasizing circular business networks and partnerships can help organizations build collaborative relationships with stakeholders in their value chain. By promoting circular business practices, organizations can create a shared vision and goals for achieving sustainability and minimizing waste, which can foster collaboration and trust among stakeholders (Eisenreich et al., 2022). On the other hand, promoting standardization and interoperability can help overcome barriers to collaboration by creating a common language and framework for sharing information and resources in a CE paradigm. By promoting standardization, organizations can improve communication and coordination among stakeholders, which can lead to more efficient and effective collaboration. Finally, provisions for resource sharing can encourage stakeholder collaboration by allowing organizations to share resources such as equipment, facilities, and personnel to optimize the use of resources in a CE. This can help organizations reduce costs and increase efficiency, while also promoting collaboration and the development of new ideas and innovations (Massaro et al., 2021).

'Facilitating communication and mutual respect (FA2)'; Enabling decentralized decision making (FA13) and 'Advocating circular lifecycle thinking approach (FA4)' comes at the fourth level of the dependence driver diagram. Facilitating communication and mutual respect (FA2) can help to establish trust and collaboration among stakeholders. Effective communication can ensure that all stakeholders have a clear understanding of the CE objectives, which can lead to better decision-making and collaboration. 'Enabling decentralized decision making (FA13)' could offer stakeholders with greater autonomy and decision-making power. Decentralized decision-making can aid to ensure that all stakeholders have a voice in the decision-making process, which can intensify their assurance to the CE initiatives. 'Advocating circular lifecycle thinking approach (FA4)' can encourage stakeholders to think holistically about the product lifecycle, from design to disposal. A circular lifecycle approach can promote the reuse, repair, and recycling of products, which can reduce waste and improve resource efficiency (Verma et al., 2022).

'Maintaining value chain collaboration (FA11)' and 'Opportunities for collaborative technology exchange (FA5)' comes at the fifth level in the ISM analysis. In CE, stakeholders need to work together to create closed-loop value chain that prioritizes the reuse, repair, and recycling of products. Maintaining collaboration among stakeholders in the value chain can ensure that products are designed for circularity, and that materials and products are reused and recycled effectively. This can lead to more efficient use of resources, reduced waste, and increased sustainability. Collaborative technology exchange can help stakeholders share knowledge and best practices, which can lead to more effective implementation of CE initiatives. For example, organizations can share information about new circular business models, such as product-as-a-service or sharing platforms, which can increase resource efficiency and reduce waste (Gusmerotti et al., 2019). This can lead to more innovative solutions and better outcomes for all stakeholders.

'Facilitators ensuring technological readiness (FA10)' and 'Emphasizing circular business networks and partnerships (FA6)' occupies the sixth level in the analysis. 'Ensuring technological readiness (FA10)' is a key practice of I4.0 in achieving stakeholder collaboration in a CE. Technology plays a crucial part in enabling the CE to function effectively, and companies need to ensure that they have the necessary tools and infrastructure to support circular practices. 'Emphasizing circular business networks and partnerships (FA6)' is another potential facilitator of I4.0 and stakeholder collaboration in a CE paradigm. Collaboration and partnership among stakeholders are key to achieving a CE, as it requires the involvement and cooperation of various actors, including suppliers, manufacturers, retailers, and consumers. By emphasizing circular business networks and partnerships, stakeholders can work together towards common goals, share resources and knowledge, and develop innovative circular business models (Li et al., 2020).

'Finally advocating circular lifecycle thinking approach (FA4)', 'Providing training and capacity building programs (FA8)', and 'promoting standardization and interoperability (FA7)' emerges at the last level of the diagram. 'Advocating a circular lifecycle thinking approach (FA4)' can help in promoting a common understanding among stakeholders about the importance of circularity and how it can be incorporated into their operations. This shared vision can facilitate collaboration by aligning the objectives of different stakeholders towards the common goal of achieving CE. 'Providing training and capacity building programs (FA8)' can help stakeholders acquire the necessary skills and knowledge to operate within CE. This can improve the efficiency of operations and foster collaboration by encouraging stakeholders to work together towards achieving a CE. ‘Promoting standardization and interoperability (FA7)’ can facilitate collaboration by providing a common platform for stakeholders to interact and exchange information. This can help in creating a seamless flow of goods, services, and information across different stages of the value chain, thus promoting circular practices (Pfaff, 2023).

The ISM-based model was validated using the MICMAC technique, which involved categorizing the drivers into four groups: independent, dependent, linkage, and autonomous. The results of MICMAC analysis shows that ‘ensuring transparency through circular supply chain visibility (FA12)’, ‘maintaining value chain collaboration (FA11)’ and ‘providing training and capacity building programs (FA8)’ are the independent facilitators as they exhibit high driving power but weak dependence power. The dependent facilitators emerge to be ‘emphasizing circular business networks and partnerships (FA6)’, ‘fostering a culture of continuous improvement (FA14)’ and ‘ensuring technological readiness (FA10)’ as they have strong dependence power but weak driving power. The remaining six facilitators act as the linkage facilitators implying that they function as a link between dependent and independent facilitators. There is no facilitator in the autonomous category elucidating that all the facilitators are equally important.

5. Managerial and policy implications

Policymakers and stakeholders who seek to promote collaboration within a circular framework are likely to find this study valuable. Furthermore, this study is expected to have academic implications, as researchers may use the framework created in this study for both theoretical and empirical analyses of emerging technologies. Implementing I4.0 practices to attain stakeholder collaboration in CE can have several managerial implications. Firstly, a clear strategy for implementing I4.0 practices in CE is essential. It should identify the key stakeholders and their roles, as well as the objectives and outcomes of the collaboration. It needs to be ensured that the necessary technologies are in place is crucial to implementing I4.0 practices (Arranz et al., 2022). This includes investing in new technologies and upgrading existing ones. Collaboration with other businesses and organizations is essential towards developing a CE. Building a network of partnerships and business relationships can help to share knowledge, resources, and expertise. Employees are required to be trained and upskilled to conduct new technologies and processes associated with I4.0. Capacity building programs can help to ensure that employees have the necessary skills and knowledge required to implement circular practices (Jabbour et al., 2019). Overall, implementing I4.0 practices to attain stakeholder collaboration in a CE requires a strategic approach that emphasizes collaboration, technological readiness, standardization, and training. By implementing these practices, organizations can work towards achieving a more sustainable and circular practices, which benefits all stakeholders. On the other hand, the policy implications for implementing I4.0 practices to attain stakeholder collaborations in CE involve creating a supportive environment that encourages innovation, collaboration, and responsible use of technology to achieve Sustainable Development Goals (SDGs) (Fonseca, 2022; Murthy et al., 2022).

6. Conclusion, limitation and scope for future research

The concept of I4.0 creates opportunities for CE by leveraging advanced digital technologies that support sustainability initiatives. One of the ways of achieving circularity through I4.0 is managing stakeholders' collaborations. In this accord, this study efforts to address the gap in the literature in terms of facilitators of I4.0 practices to attain stakeholders' collaboration. This study is one of the potential literature in developing a relationship between I4.0 and stakeholders' collaborations. The objective of the study was fulfilled by adopting a rigorous mixed method approach. Firstly, an extensive literature review was performed to recognize the facilitators of I4.0 practices for attaining stakeholders' collaboration in the purview of CE. Secondly, an integrated approach of BWM and ISM MICMAC analysis was used to assess the interconnectedness of these facilitators.

The study highlights that the facilitators of I4.0 practices aim at achieving stakeholder collaboration are interdependent and can significantly impact each other. The framework proposed in this study can help policymakers comprehend the different facilitators and their influence on stakeholder collaboration in the circular economy context. This understanding can benefit decision-makers and managers in improving the manufacturing system's efficiency and attaining favorable long-term outcomes. However, this study has limitations that must be acknowledged. Firstly, the opinions of academic and industry experts within the manufacturing sector were the basis of the study, particularly for the BWM and ISM techniques, introducing the possibility of subjective bias in the findings. Secondly, the study focused on 14 facilitators, which is not an exhaustive list, and additional relevant facilitators may be identified in future studies. Finally, I4.0's contribution in the CE is continuously evolving, necessitating an update of the study's findings in the coming years. In the future, scholars may enhance precision and reduce ambiguity by integrating fuzzy sets with the BWM-ISM hybrid method proposed in this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Ali, A., Almaiah, M. A., Hajjej, F., Pasha, M. F., Fang, O. H., Khan, R., & Zakarya, M. (2022). An industrial IoT-based blockchain-enabled secure searchable encryption approach for healthcare systems using neural network. *Sensors*, *22*(2), 572.

Anam, M. Z., Bari, A. M., Paul, S. K., Ali, S. M., & Kabir, G. (2022). Modelling the drivers of solar energy development in an emerging economy: Implications for sustainable development goals. *Resources, Conservation and Recycling Advances*, *13*, 200068. https://doi.org/10.1016/j.rcradv.2022.200068

Anbumozhi, V., Ramanathan, K., & Wyes, H. (2020). *Assessing the readiness for industry 4.0 and the circular economy*. Economic Research Institute for ASEAN and East Asia.

Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalisation as an enabler of circular economy. *Procedia CIRP*, *73*, 45–49. https://doi.org/10.1016/j.procir.2018.04.027

Arranz, C. F., Sena, V., & Kwong, C. (2022). Institutional pressures as drivers of circular economy in firms: A machine learning approach. *Journal of Cleaner Production*, *355*, 131738. https://doi.org/10.1016/j.jclepro.2022.131738

Attri, R., Dev, N., & Sharma, V. (2013). Interpretive structural modelling (ISM) approach: An overview. *Research Journal of Management Sciences*, *2319*(2), 1171.

Awan, U., Sroufe, R., & Shahbaz, M. (2021). Industry 4.0 and the circular economy: A literature review and recommendations for future research. *Business Strategy and the Environment*, *30*(4), 2038–2060. https://doi.org/10.1002/bse.2731

Baah, C., Afum, E., Agyabeng-Mensah, Y., & Agyeman, D. O. (2022). Stakeholder influence on adoption of circular economy principles: Measuring implications for satisfaction and green legitimacy. *Circular Economy and Sustainability, Circular Economy and Sustainability*, *2*(1), 91–111. https://doi.org/10.1007/s43615-021-00093-2

Bag, S., Rahman, M. S., Srivastava, G., Shore, A., & Ram, P. (2023). Examining the role of virtue ethics and big data in enhancing viable, sustainable, and digital supply chain performance. *Technological Forecasting and Social Change*, *186*, 122154. https://doi.org/10.1016/j.techfore.2022.122154

Barrane, F. Z., Ndubisi, N. O., Kamble, S., Karuranga, G. E., & Poulin, D. (2021). Building trust in multi-stakeholder collaborations for new product development in the digital transformation era. *Benchmarking: An International Journal*, *28*(1), 205–228. https://doi.org/10.1108/BIJ-04-2020-0164

Bhatia, M. S., & Kumar, S. (2022). Linking stakeholder and competitive pressure to Industry 4.0 and performance: Mediating effect of environmental commitment and green process innovation. *Business Strategy and the Environment*, *31*(5), 1905–1918. https://doi.org/10.1002/bse.2989

Blunck, E., & Werthmann, H. (2017). Industry 4.0–an opportunity to realize sustainable manufacturing and its potential for a circular economy. *DIEM: Dubrovnik International Economic Meeting*, *3*(1), 644–666.

Bonilla, S. H., Silva, H. R., Terra da Silva, M., Franco Gonçalves, R., & Sacomano, J. B. (2018). Industry 4.0 and sustainability implications: A scenario-based analysis of the impacts and challenges. *Sustainability*, *10*(10), 3740. https://doi.org/10.3390/su10103740

Bosman, L., Hartman, N., & Sutherland, J. (2020). How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. *Journal of Manufacturing Technology Management*, *31*(5), 1117–1141. https://doi.org/10.1108/JMTM-09-2018-0283

Bryson, J. M. (2004). What to do when stakeholders matter. Stakeholder identification and analysis techniques. *Public Management Review*, *6*(1), 21–53. https://doi.org/10.1080/14719030410001675722

Červený, L., Sloup, R., & Červená, T. (2022). The potential of smart factories and innovative Industry 4.0 technologies—A case study of different-sized companies in the furniture Industry in Central Europe. *Forests*, *13*(12), 2171. https://doi.org/10.3390/f13122171

Chang, R. D., Zuo, J., Zhao, Z. Y., Zillante, G., Gan, X. L., & Soebarto, V. (2017). Evolving theories of sustainability and firms: History, future directions and implications for renewable energy research. *Renewable and Sustainable Energy Reviews*, *72*, 48–56. https://doi.org/10.1016/j.rser.2017.01.029

Ciliberto, C., Szopik-Depczyńska, K., Tarczyńska-Łuniewska, M., Ruggieri, A., & Ioppolo, G. (2021). Enabling the circular economy transition: A sustainable lean manufacturing recipe for Industry 4.0. *Business Strategy and the Environment*, *30*(7), 3255–3272. https://doi.org/10.1002/bse.2801

Crane, A., & Ruebottom, T. (2011). Stakeholder theory and social identity: Rethinking stakeholder identification. *Journal of Business Ethics*, *102*(S1), 77–87. https://doi.org/10.1007/s10551-011-1191-4

Dahlgaard, J. J., Chen, C.-K., Jang, J.-Y., Banegas, L. A., & Dahlgaard-Park, S. M. (2013). Business excellence models: Limitations, reflections and further development. *Total Quality Management and Business Excellence*, *24*(5–6), 519–538. https://doi.org/10.1080/14783363.2012.756745

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*, 383–394. https://doi.org/10.1016/j.ijpe.2018.08.019

De Angelis, R. (2021). *Circular economy business models: A repertoire of theoretical relationships and a research agenda, circular economy and sustainability*. Springer International Publishing. No. 0123456789.

Dikhanbayeva, D., Tokbergenova, A., Lukhmanov, Y., Shehab, E., Pastuszak, Z., & Turkyilmaz, A. (2021). Critical factors of industry 4.0 implementation in an emerging country: Empirical study. *Future Internet*, *13*(6), 137. https://doi.org/10.3390/fi13060137

Dranka, G. G., & Ferreira, P. (2020). Towards a smart grid power system in Brazil: Challenges and opportunities. *Energy Policy*, *136*, 111033. https://doi.org/10.1016/j.enpol.2019.111033

Dwivedi, A., Agrawal, D., Jha, A., & Mathiyazhagan, K. (2023). Studying the interactions among Industry 5.0 and circular supply chain: Towards attaining sustainable development. *Computers & Industrial Engineering*, *176*, 108927. https://doi.org/10.1016/j.cie.2022.108927

Eisenreich, A., Füller, J., Stuchtey, M., & Gimenez-Jimenez, D. (2022). Toward a circular value chain: Impact of the circular economy on a company's value chain processes. *Journal of Cleaner Production*, *378*, 134375. https://doi.org/10.1016/j.jclepro.2022.134375

EMF. (2015). Towards the circular economy: Economic and business rationale for an accelerated transition. Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf.

Fobbe, L., & Hilletofth, P. (2023). Moving toward a circular economy in manufacturing organizations: The role of circular stakeholder engagement practices. *The International Journal of Logistics Management*, *34*(3), 674–698. https://doi.org/10.1108/IJLM-03-2022-0143

Fonseca, L. (2022). The EFQM 2020 model. A theoretical and critical review. *Total Quality Management & Business Excellence*, *33*(9–10), 1011–1038. https://doi.org/10.1080/14783363.2021.1915121

Fonseca, L. M., Domingues, J. P., Pereira, M. T., Martins, F. F., & Zimon, D. (2018). Assessment of circular economy within Portuguese organisations. *Sustainability*, *10*(7), 2521. https://doi.org/10.3390/su10072521

Freeman, R. E. (1984). *Strategic Management: Stakeholder approach*. Pitman.

Freeman, R. E., Kujala, J., Sachs, S., & Stutz, C. (2017). Stakeholder engagement: Practicing the ideas of stakeholder theory. In R. E. Freeman, J. Kujala, & S. Sachs (Eds.), *Stakeholder engagement: Clinical research cases* (pp. 1–12). Springer International Publishing. https://doi.org/10.1007/978-3-319-62785-4_1

Galati, F., & Bigliardi, B. (2019). Industry 4.0: Emerging themes and future research avenues using a text mining approach. *Computers in Industry*, *109*, 100–113. https://doi.org/10.1016/j.compind.2019.04.018

Genovese, A., Acquaye, A. A., Figueroa, A., & Lenny Koh, S. C. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega*, *66*, 344–357. https://doi.org/10.1016/j.omega.2015.05.015

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, *252*, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Ghobakhloo, M., Iranmanesh, M., Grybauskas, A., Vilkas, M., & Petraitė, M. (2021). Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation. *Business Strategy and the Environment*, *30*(8), 4237–4257. https://doi.org/10.1002/bse.2867

Gholami, H., Abu, F., Lee, J. K. Y., Karganroudi, S. S., & Sharif, S. (2021). Sustainable manufacturing 4.0—pathways and practices. *Sustainability*, *13*(24), 13956. https://doi.org/10.3390/su132413956

Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: A supply chain perspective. *International Journal of Production Research*, *56*(1–2), 278–311. https://doi.org/10.1080/00207543.2017.1402141

Gupta, H., & Barua, M. K. (2017). Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS. *Journal of Cleaner Production*, *152*, 242–258. https://doi.org/10.1016/j.jclepro.2017.03.125

Gusmerotti, N. M., Testa, F., Corsini, F., Pretner, G., & Iraldo, F. (2019). Drivers and approaches to the circular economy in manufacturing firms. *Journal of Cleaner Production*, *230*, 314–327. https://doi.org/10.1016/j.jclepro.2019.05.044

H€orisch, J., Freeman, R. E., & Schaltegger, S. (2014). Applying stakeholder theory in sustainability management: Links, similarities, dissimilarities, and a conceptual framework. *Organization and Environment*, *27*(4), 328–346. https://doi.org/10.1177/1086026614535786

Hettiarachchi, B. D., Seuring, S., & Brandenburg, M. (2022). Industry 4.0-driven operations and supply chains for the circular economy: A bibliometric analysis. *Operations Management Research*, *15*(3–4), 858–878. https://doi.org/10.1007/s12063-022-00275-7

Ijaz Baig, M., & Yadegaridehkordi, E. (2023). Exploring moderating effects of industry 4.0 adoption on sustainable performance of Malaysian manufacturing organizations. *Journal of Industrial and Production Engineering*, *40*(4), 271–286. https://doi.org/10.1080/21681015.2023.2190766

Ivanov, D., & Dolgui, A. (2021). A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. *Production Planning & Control*, *32*(9), 775–788. https://doi.org/10.1080/09537287.2020.1768450

Jabbour, C. J. C., Jabbour, A. B. L. D. S., Sarkis, J., & Filho, M. G. (2019). Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda. *Technological Forecasting and Social Change*, *144*, 546–552. https://doi.org/10.1016/j.techfore.2017.09.010

Jonak, Ł., Rudnicka, A., & Włoch, R. (2020). Digitalization of Supply Chain Transparency: The Case of ChainReact. In K. Grzybowska, A. Awasthi, & R. Sawhney(Eds.), *Sustainable Logistics and Production in Industry 4.0*. Cham: EcoProduction. Springer. https://doi.org/10.1007/978-3-030-33369-0_6

Kayikci, Y., Kazancoglu, Y., Gozacan-Chase, N., & Lafci, C. (2022). Analyzing the drivers of smart sustainable circular supply chain for sustainable development goals through stakeholder theory. *Business Strategy and the Environment*, *31*(7), 3335–3353. https://doi.org/10.1002/bse.3087

Khan, S., Kaushik, M. K., Kumar, R., & Khan, W. (2023). Investigating the barriers of blockchain technology integrated food supply chain: A BWM approach. *Benchmarking: An International Journal*, *30*(3), 713–735. https://doi.org/10.1108/BIJ-08-2021-0489

Kumar, R., & Goel, P. (2022). Exploring the domain of interpretive structural modelling (ISM) for sustainable future panorama: A bibliometric and content analysis. *Archives of Computational Methods in Engineering*, *29*(5), 2781–2810. https://doi.org/10.1007/s11831-021-09675-7

Lahane, S., Kant, R., & Shankar, R. (2020). Circular supply chain management: A state-of-art review and future opportunities. *Journal of Cleaner Production*, *258*, 120859. https://doi.org/10.1016/j.jclepro.2020.120859

Lardo, A., Mancini, D., Paoloni, N., & Russo, G. (2020). The perspective of capability providers in creating a sustainable I4. 0 environment. *Management Decision*, *58*(8), 1759–1777.

Liang, F., Brunelli, M., & Rezaei, J. (2020). Consistency issues in the best worst method: Measurements and thresholds. *Omega*, *96*, 102175.

Liang, Y., Wang, H., & Zhao, X. (2022). Analysis of factors affecting economic operation of electric vehicle charging station based on DEMATEL-ISM. *Computers & Industrial Engineering*, *163*, 107818. https://doi.org/10.1016/j.cie.2021.107818

Li, Y., Dai, J., & Cui, L. (2020). The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. *International Journal of Production Economics*, *229*, 107777. https://doi.org/10.1016/j.ijpe.2020.107777

Lidenhammar, R. (2015). *Hopping on the service bandwagon towards a circular economy-consumer acceptance of product-service systems for home furniture* [IIIEE Master thesis].

Lin, B., Wu, W., & Song, M. (2019). Industry 4.0: Driving factors and impacts on firm's performance: An empirical study on China's manufacturing industry. *Annals of Operations Research*, *277*(1), 1–21. https://doi.org/10.1007/s10479-019-03197-z

Machado, C. G., Winroth, M. P., & Ribeiro da Silva, E. H. D. (2020). Sustainable manufacturing in Industry 4.0: An emerging research agenda. *International Journal of Production Research*, *58*(5), 1462–1484. https://doi.org/10.1080/00207543.2019.1652777

Massaro, M., Secinaro, S., Dal Mas, F., Brescia, V., & Calandra, D. (2021). Industry 4.0 and circular economy: An exploratory analysis of academic and practitioners' perspectives. *Business Strategy and the Environment*, *30*(2), 1213–1231. https://doi.org/10.1002/bse.2680

Mastos, T. D., Nizamis, A., Terzi, S., Gkortzis, D., Papadopoulos, A., Tsagkalidis, N., Ioannidis, D., Votis, K., & Tzovaras, D. (2021). Introducing an application of an industry 4.0 solution for circular supply chain management. *Journal of Cleaner Production*, *300*, 126886. https://doi.org/10.1016/j.jclepro.2021.126886

Mian, S. H., Salah, B., Ameen, W., Moiduddin, K., & Alkhalefah, H. (2020). Adapting universities for sustainability education in industry 4.0: Channel of challenges and opportunities. *Sustainability*, *12*(15), 6100.

Moktadir, M. A., Dwivedi, A., Khan, N. S., Paul, S. K., Khan, S. A., Ahmed, S., & Sultana, R. (2021). Analysis of risk factors in sustainable supply chain management in an emerging economy of leather industry. *Journal of Cleaner Production*, *283*, 124641. https://doi.org/10.1016/j.jclepro.2020.124641

Mondal, S., Singh, S., & Gupta, H. (2023). Achieving technological transformation and social sustainability: An Industry 4.0 perspective. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2023.3246637

Murthy, M. A. N., Sangwan, K. S., & Narahari, N. S. (2022). Tracing the evolution of EFQM and its relationship with Industry 4.0. *Total Quality Management & Business Excellence*, *33*(15–16), 1737–1776. https://doi.org/10.1080/14783363.2021.1999802

Niehoff, S. (2022). Aligning digitalisation and sustainable development? Evidence from the analysis of worldviews in sustainability reports. *Business Strategy and the Environment*, *31*(5), 2546–2567. https://doi.org/10.1002/bse.3043

Nosalska, K., Piątek, Z. M., Mazurek, G., & Rządca, R. (2019). Industry 4.0: Coherent definition framework with technological and organizational interdependencies. *Journal of Manufacturing Technology Management*, *31*(5), 837–862. https://doi.org/10.1108/JMTM-08-2018-0238

Oláh, J., Aburumman, N., Popp, J., Khan, M. A., Haddad, H., & Kitukutha, N. (2020). Impact of industry 4.0 on environmental sustainability. *Sustainability*, *12*(11), 4674.

Patil, A., Dwivedi, A., & Moktadir, M. A. (2023). Big data-Industry 4.0 readiness factors for sustainable supply chain management: Towards circularity. *Computers & Industrial Engineering*, *178*, 109109. https://doi.org/10.1016/j.cie.2023.109109

Patyal, V. S., Sarma, P. R. S., Modgil, S., Nag, T., & Dennehy, D. (2022). Mapping the links between industry 4.0, circular economy and sustainability: A systematic literature review. *Journal of Enterprise Information Management*, *35*(1), 1–35.

Paulraj, A., Lado, A. A., & Chen, I. J. (2008). Inter-organizational communication as a relational competency: Antecedents and performance outcomes in collaborative buyer–supplier relationships. *Journal of Operations Management*, *26*(1), 45–64. https://doi.org/10.1016/j.jom.2007.04.001

Peiró-Signes, Á., Cervelló-Royo, R., & Segarra-Oña, M. (2022). Can a country's environmental sustainability exert influence on its economic and financial situation? The relationship between environmental performance indicators and country risk. *Journal of Cleaner Production*, *375*, 134121.

Pfaff, Y. M. (2023). Agility and digitalization: Why strategic agility is a success factor for mastering digitalization – evidence from Industry 4.0 implementations across a supply chain. *International Journal of Physical Distribution & Logistics Management*, *53*(5/6), 660–684. https://doi.org/10.1108/IJPDLM-06-2022-0200

Pham, T. T., Kuo, T. C., Tseng, M. L., Tan, R. R., Tan, K., Ika, D. S., & Lin, C. J. (2019). Industry 4.0 to accelerate the circular economy: A case study of electric scooter sharing. *Sustainability*, *11*(23), 6661. https://doi.org/10.3390/su11236661

Rahman, M. A., Zaman, N., Asyhari, A. T., Al-Turjman, F., Bhuiyan, M. Z. A., & Zolkipli, M. F. (2020). Data-driven dynamic clustering framework for mitigating the adverse economic impact of covid-19 lockdown practices. *Sustainable Cities and Society*, *62*, 102372.

Rajput, S., & Singh, S. P. (2019). Connecting circular economy and industry 4.0. *International Journal of Information Management*, *49*, 98–113. https://doi.org/10.1016/j.ijinfomgt.2019.03.002

Raut, R. D., Narkhede, B., & Gardas, B. B. (2017). To identify the critical success factors of sustainable supply chain management practices in the context of oil and gas industries: ISM approach. *Renewable and Sustainable Energy Reviews*, *68*, 33–47. https://doi.org/10.1016/j.rser.2016.09.067

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, *53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009

Rezaei, J. (2020). A concentration ratio for nonlinear best worst method. *International Journal of Information Technology & Decision Making*, *19*(3), 891–907. https://doi.org/10.1142/S0219622020500170

Rezaei, J., Kothadiya, O., Tavasszy, L., & Kroesen, M. (2018). Quality assessment of airline baggage handling systems using SERVQUAL and BWM. *Tourism Management*, *66*, 85–93. https://doi.org/10.1016/j.tourman.2017.11.009

Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between circular economy and Industry 4.0: A systematic literature review. *International Journal of Production Research*, *58*(6), 1662–1687. https://doi.org/10.1080/00207543.2019.1680896

Shah, M. U., & Bookbinder, J. H. (2022). Stakeholder theory and supply chains in the circular economy. In L. Bals, W. L. Tate, & L. M. Ellram (Eds.), *Circular economy supply chains. From chains to systems* (pp. 129–148). Emerald Publishing. https://doi.org/10.1108/978-1-83982-544-620221007

Shet, S. V., & Pereira, V. (2021). Proposed managerial competencies for Industry 4.0–implications for social sustainability. *Technological Forecasting and Social Change*, *173*, 121080. https://doi.org/10.1016/j.techfore.2021.121080

Sony, M., Antony, J., Tortorella, G., McDermott, O., & Gutierrez, L. (2022). Determining the critical failure factors for Industry 4.0: An exploratory sequential mixed method study. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2022.3159860

Varela, L., Putnik, G., & Romero, F. (2023). Collaborative manufacturing and management contextualization in the Industry 4.0 based on a systematic literature review. *International Journal of Management Science and Engineering Management*, 1–18. https://doi.org/10.1080/17509653.2023.2174200

Veile, J. W., Kiel, D., Mueller, J. M., & Voigt, K.-I. (2020). Lessons learned from Industry 4.0 implementation in the German manufacturing industry. *Journal of Manufacturing Technology Management*, *31*(5), 977–997. https://doi.org/10.1108/JMTM-08-2018-0270

Verma, P., Kumar, V., Daim, T., Sharma, N. K., & Mittal, A. (2022). Identifying and prioritizing impediments of industry 4.0 to sustainable digital manufacturing: A mixed method approach. *Journal of Cleaner Production*, *356*, 131639. https://doi.org/10.1016/j.jclepro.2022.131639

Warfield, J. N. (1974). Developing interconnection matrices in structural modeling. *IEEE Transactions on Systems, Man, and Cybernetics*, *1*(1), 81–87. https://doi.org/10.1109/TSMC.1974.5408524

Yadav, N., & Al Owad, A. (2022). Comparing viewpoints of top management, consultants and employees about Lean Six Sigma. *Journal of Manufacturing Technology Management*, *33*(6), 1150–1170. (ahead-of-print). https://doi.org/10.1108/JMTM-12-2021-0497

Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J. A., Kumar, V., & Batista, L. (2020). A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. *Computers in Industry*, *122*, 103280. https://doi.org/10.1016/j.compind.2020.103280

Zheng, L. J., Wang, Y. A., Lin, H. Y., & Liu, W. (2023). Understanding circular economy adoption by SMEs: A case study on organizational legitimacy and Industry 4.0. *Industrial Management & Data Systems*, *123*(4), 1157–1177. https://doi.org/10.1108/IMDS-04-2022-0266

Appendices

Appendix A: Structural Self-Interaction Matrix (SSIM)

S. No.	FA14	FA13	FA12	FA11	FA10	FA9	FA8	FA7	FA6	FA5	FA4	FA2
FA2	O	O	O	A	O	A	V	O	O	O	X	
FA4	O	A	O	O	O	O	V	O	O	O		
FA5	V	A	O	O	V	V	A	V	A			
FA6	O	O	A	O	O	O	A	A				
FA7	V	O	O	O	O	V	A					
FA8	V	V	V	V	V	V						
FA9	O	A	O	O	V							
FA10	V	V	O	V								
FA11	O	V	A									
FA12	O	O										
FA13	O											
FA14												

Appendix B: Initial Reachability Matrix (IRM)

S.No.	FA2	FA4	FA5	FA6	FA7	FA8	FA9	FA10	FA11	FA12	FA13	FA14
FA2	1	1	0	0	0	1	0	0	0	0	0	0
FA4	1	1	0	0	0	1	0	0	0	0	0	0
FA5	0	0	1	0	1	0	1	1	0	0	0	1
FA6	0	0	1	1	0	0	0	0	0	0	0	0
FA7	0	0	0	1	1	0	1	0	0	0	0	1
FA8	0	0	1	1	1	1	1	1	1	1	1	1
FA9	1	0	0	0	0	0	1	1	0	0	0	0
FA10	0	0	0	0	0	0	0	1	1	0	1	1
FA11	1	0	0	0	0	0	0	1	1	0	1	0
FA12	0	0	0	1	0	0	0	0	1	1	0	0
FA13	0	1	1	0	0	0	1	0	0	0	1	0
FA14	0	0	0	0	0	0	0	0	0	0	0	1

Appendix C: Final Reachability Matrix (FRM)

S. No.	FA2	FA4	FA5	FA6	FA7	FA8	FA9	FA10	FA11	FA12	FA13	FA14
FA2	1	1	1*	1*	1*	1	1*	1*	1*	1*	1*	1*
FA4	1	1	1*	1*	1*	1	1*	1*	1*	1*	1*	1*
FA5	1*	0	1	1*	1	0	1	1	0	0	1*	1
FA6	0	0	1	1	1*	0	1*	1*	0	0	0	1*
FA7	1*	0	1*	1	1	0	1	1*	0	0	0	1
FA8	1*	1*	1	1	1	1	1	1	1	1	1	1
FA9	1	1*	0	0	0	1*	1	1	0	0	1*	1*
FA10	0	1*	1*	0	0	0	1*	1	1	0	1	1
FA11	1	1*	1*	0	0	1*	1*	1	1	0	1	1*
FA12	1*	0	1*	1	0	0	0	1*	1	1	1*	0
FA13	1*	1	1	0	1*	1*	1	1*	0	0	1	1*
FA14	0	0	0	0	0	0	0	0	0	0	0	1

Appendix D: Iterationtempfor level partitioning

Code	Reachability Set	Antecedent Set	Intersection Set	Level
FA2	2,4,5,6,7,8,9,10,11,12,13,14	2,4,5,7,8,9,11,12,	2,4,5,7,8,9,11,12,	
FA4	2,4,5,6,7,8,9,10,11,12,13,14	2,4,8,9,10,11,13,	2,4,8,9,10,11,13,	
FA5	2,5,6,7,9,10,13,14,	2,4,5,6,7,8,10,11,	2,5,6,7,10,13,	
FA6	5,6,7,9,10,14,	2,4,5,6,7,8,12,	5,6,7,	
FA7	2,5,6,7,9,10,14,	2,4,5,6,7,8,13,	2,5,6,7,	
FA8	2,4,5,6,7,8,9,10,11,12,13,14	2,4,8,9,11,13,	2,4,8,9,11,13,	
FA9	2,4,8,9,10,13,14,	2,4,5,6,7,8,9,10,	2,4,8,9,10,13,	
FA10	4,5,9,10,13,14,	2,4,5,6,7,8,9,10,	4,5,9,10,13,	
FA11	2,4,5,8,9,10,11,13,	2,4,8,11,12,	2,4,8,11,	
FA12	2,5,6,10,11,12,13,	2,4,8,12,	2,12,	
FA13	2,4,5,7,8,9,10,13,	2,4,5,8,9,10,11,12,	2,4,5,8,9,10,13,	
FA14	14	2,4,5,6,7,8,9,10,	14	1

Appendix E: Iteration (temp-tempconsolidated) for level partitioning

Code	Reachability Set	Antecedent Set	Intersection Set	Level
FA2	2,4,8,11,12,13,	2,4,8,11,12,13,	2,4,8,11,12,13,	4
FA4	4,8,	4,8,	4,8,	7
FA5	2,5,6,7,13,	2,4,5,6,7,8,11,12,13,	2,5,6,7,13,	3
FA6	5,6,7,	2,4,5,6,7,8,12,	5,6,7,	3
FA7	2,5,6,7,	2,4,5,6,7,8,13,	2,5,6,7,	3
FA8	4,8,	4,8,	4,8,	7
FA9	2,4,8,9,10,13,	2,4,5,6,7,8,9,10,11,13,	2,4,8,9,10,13,	2
FA10	4,5,9,10,13,	2,4,5,6,7,8,9,10,11,12,13	4,5,9,10,13,	2
FA11	4,8,11,	4,8,11,12,	4,8,11,	5
FA12	10,	4,8,12,	10,	6
FA13	2,4,8,13,	2,4,8,11,12,13,	2,4,8,13,	4
FA14	14,	2,4,5,6,7,8,9,10,11,13,14	14,	1

Appendix F: Experts Details

Experts	Domain	Experience
Expert 1,2,3	Operations manager	>10 years
Expert 4,5	Product manager (I4.0)	>5 years
Expert 6,7,8	Senior manager (Consulting)	>12 years
Expert 9	I4.0 Researcher	>3 years
Expert 10,11	Academician	>15 years