**ORIGINAL RESEARCH**

# Modeling the blockchain readiness challenges for product recovery system

Ashish Dwivedi[1] · Dindayal Agrawal[2] · Sanjoy Kumar Paul[3] · Saurabh Pratap[4]

## Abstract

Product Recovery System (PRS) transfers products from their typical final place to their source to arrest some value on the product. There are obstructions, such as costs, associated with the modification of accounts and assessment of products and refunds associated with the implementation of PRS. Blockchain Technology (BCT) emerged as an innovative approach to constructing trust in a trust less environment and assures the availability, traceability, and security in data management. It also presents a valuable solution to PRS. This study aims to analyze the Blockchain Readiness Challenges (BRCs) to PRS in the context of manufacturing industries. The study observes 20 readiness challenges linked with the implementation of BCT in PRS. The BRCs are identified from the literature survey and confirmed after consequent examinations with industry experts and researchers. The study employed a Multi-Criteria Decision-Making (MCDM) i.e., the Decision-Making Trial And Evaluation Laboratory (Fuzzy DEMATEL) approach to find the cause-and-effect interactions to prioritize BRCs. The Maximum Mean De-Entropy (MMDE) algorithm was adopted to establish the threshold value based on the information entropy of the interactions among the BRCs for PRS. The fuzzy set theory was adopted to tackle the uncertainty and vagueness of personnel biases and data deficiency problems. The findings from this study reveal that inadequate financing for PRS exercises, lack of governance and standards, and security challenges to BCT implementation are the most influential readiness challenges for the adoption of blockchain in PRS. The study is useful to manufacturing organizations for identifying the potential BRCs to implement PRS among all existing readiness challenges so that they

✉ Sanjoy Kumar Paul
   sanjoy.paul@uts.edu.au

   Ashish Dwivedi
   ashish0852@gmail.com

   Dindayal Agrawal
   ddagrawal123@gmail.com

   Saurabh Pratap
   s.pratapiitkgp@gmail.com

1  Jindal Global Business School, O.P. Jindal Global University, Sonipat, India

2  Department of Management Studies, Indian Institute of Technology, Delhi, India

3  UTS Business School, University of Technology Sydney, Sydney, Australia

4  Department of Mechanical Engineering, Indian Institute of Technology (IIT BHU), Varanasi, India

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can take suitable measures before proceeding to adopt blockchain in PRS. The managers are suggested to eliminate the readiness challenges and widen the blockchain technology adoption in PRS.

**Keywords** Readiness challenges · Blockchain technology · Product recovery system · Multi-criteria decision-making · Fuzzy DEMATEL

# 1 Introduction

In the past decade, product recovery system (PRS), comprised of the movement of a product from the customer to the manufacturer by increasing additional movements in the revenue from customers and recycling and reprocessing consumed products, has acquired more consideration among researchers and society (Dwivedi & Madaan, 2020). In some countries, there are laws and regulations to accumulate the used products by their manufacturers. Further, PRS benefits organizations to attain financial profits through used products and recycled/remanufactured parts. In the era of digitalization, several innovative technologies are executed in the PRS to trace the movement of products between the arbitrators in the supply network (Akter et al., 2020; Kouhizadeh & Sarkis, 2018). Additionally, Internet of Things (IoT) sensors are embedded in products to maintain the tracking of parts in the product and store information regarding their condition (Alqahtani et al., 2019). It provides systematic product management both at the product and component level. The amalgamation of information, decision-making, and digital technologies in PRS result in a digitalized PRS. However, the technologies executed in the PRS are centralized and monitored by a dominant central authority (O'Dair and Beaven, 2017). This approach of the dominant central authority leads to trust issues, such as tampering, corruption, and fraud.

The BCT is adopted to enhance business in products and components, including marketing, buying, selling, planning, control, visibility, traceability, and reliability (Patil et al., 2020; Rezaee, 2019). BCT protects data by sharing business information, sustaining business interactions, and organizing business negotiations (Kamble et al., 2019; Zheng et al., 2020). Further, BCT contributes to increased efficiency, control, and facilitating commercial transactions (Luo & Choi, 2021). BCT enhances product recovery planning and decision-making by eradicating the ambiguity specific to the valuable life of returned products (Tozanli et al., 2020). This efficiency makes the BCT more essential for enterprises due to its stability in providing a tighter control structure while enhancing transparency (Hungud et al., 2020). In PRS, a series of blockchain-digitization concerns are evident across the different stages of product movement, such as collection, separation, inspection, storage, and disassembly (Bekrar et al., 2021). The measures concerning security, traceability, and transparency can play an essential part in catering to blockchain-digitization concerns. Thus, it becomes necessary to identify the BRCs in the successful implementation of PRS.

Therefore, this paper contributes towards both the existing literature and an existing frame of convenient knowledge with the following objectives:

(a) To investigate the potential BRCs for PRS in the Indian manufacturing industry;
(b) To investigate the cause-and-effect relations among the identified potential BRCs for PRS adopting the fuzzy DEMATEL-MMDE methodology;
(c) To prioritize the identified potential BRCs for PRS and recommend managerial and practical implications.

Previous literature has been examined to identify potential BRCs for PRS in the Indian manufacturing industry to attain the above-highlighted objectives. Several brainstorming sessions were organized with the industry managers from the Indian manufacturing industry to confirm the potential BRCs for PRS. Further, BRCs for PRS were evaluated and prioritized, adopting the fuzzy DEMATEL-MMDE approach.

The remaining paper is presented as follows. In Sect. 2, the literature review provides an overview of previous literature specific to blockchains, digital technologies, and PRS. The research methodology and the fuzzy DEMATEL-MMDE methodology are highlighted in Sect. 3. The results and discussion are presented in Sect. 4. Managerial implications are provided in Sect. 5. Finally, conclusions and future research directions are presented in Sect. 6.

## 2 Literature review

In this section, the previous literature relevant to the problem is considered. In this deference, the previous studies specific to product recovery, blockchains, barriers and challenges to product recovery, and applications of digital technologies are highlighted. Table 1 provides a summary of previous studies in the area of PRS.

### 2.1 Recent literature on blockchain-based PRS

Present business and industry prospects have been transforming promptly, involving flexible and efficient PRSs to cater to current confrontations in sustainability. Blockchains refer to disruptive technologies for the design, coordination, movement, and management of the supply chains (Saberi et al., 2019). This section highlights the previous studies specific to blockchain technology and how it is application-specific to Sustainable Supply Chains (SSC), Closed-Loop Supply Chains (CLCS), and PRSs. Gautam et al. (2021) studied product recovery and focussed on 3R's i.e., Reduce, Reuse and Recycle products, to reduce the waste. The developed model aims to minimize energy consumption and carbon gas emission during production, shortage of products, transportation, and disposal of defective products. Sarker et al. (2009) investigated to determine the Economic Order Quantity (EOQ) and product quantity to satisfy the customer demand by the combination of new products, recovered-used products.

Kouhizadeh et al. (2021) practiced the force field theory to identify barriers to blockchain adoption. The results from the study reflect that supply chain and technological barriers are the most critical barriers for adopting BCT to manage SSCs. Zhi et al. (2021) studied the investors concerning various risk criteria in investment decision-making through blockchain information. Further, Liu et al. (2021) proposed an environmental, social, and governance reporting framework based on blockchains to facilitate the sustainability evaluation of the listed companies. The results from the study contributed towards facilitating the sustainability-level evaluation of the organizations. Further, Tozanli et al. (2020) presented the employment of IoT rooted products in a blockchain facilitated disassembly-to-order system. The study adopted a discrete event simulation model to calculate the system's expected cost. Similarly, Esmaeilian et al. (2020) summarized blockchains and Industry 4.0 for attaining sustainability in supply chains. The study discussed the four capabilities of BCT towards a sustainable supply chain. Katsaliaki et al. (2021) studied and determined the challenges for supply chain disruption. The content analysis described the type of disruption and its influence on supply chain network design.

**Table 1** Analysis of the existing literature in the present domain

| Reference | Research problem | Approach of the study | Context of the study | Considered blockchain? (Yes or No) |
|---|---|---|---|---|
| Pan et al. (2015) | Production planning and inventory control for PRS | Dynamic programming approach | General context | No |
| Sharma et al. (2016) | Benchmarking PRS alternatives in reverse logistics | Superiority and inferiority ranking (SIR) method | Manufacturing industry | No |
| Fortuna and Diyamandoglu (2017) | Optimizing of GHG emissions in PRS through reuse platforms | Optimization model | Manufacturing industry | No |
| Marconi et al. (2017) | Traceability of products and investigate sustainable factors during supply chain | Qualitative analysis | Leather Shoe industry | No |
| Marshall and Archibald (2018) | Product recovery system within an infinite planning horizon, for multiple fixed-sized productions | An EOQ lot-sizing model | Manufacturing industries | No |
| Kazancoglu et al. (2018) | Performance assessment in GSCM, which combines environmental, economics, logistics, operational, organizational | Fuzzy DEMATEL | Cement industry | No |
| De Oliveira et al. (2019) | Brazilian expanded polystyrene supply chain with circular economy | Qualitative analysis | Polystyrene industry | No |
| Dwivedi et al. (2020) | Identification of factors to implement PRS for circular economy | Fuzzy VIKOR | Manufacturing industries | No |
| Gautam et al. (2021) | Product recovery management towards a cleaner system | Mathematical model and analysis | General context | No |
| This study | Analyze the BRCs to PRS in the context of manufacturing industries | Fuzzy DEMATEL | Manufacturing industries | Yes |

Further, Varriale et al. (2020) conducted a literature review to illustrate the sustainable attributes of adopting BCT in supply chains. The study reflected the use of blockchains to improve profits for organizations. Choi et al. (2020) identified the factors that hinder organizations from merging BCT with the supply chain. The study adopted a partial least square approach for attaining the results. Vafadarnikjoo et al. (2021) analyzed the blockchain barriers for the manufacturing supply chain industry. The results identified the major barriers to implementing the supply chain network design. Shoaib et al. (2020) identified the success factors for implementing a blockchain-based supply chain. The accessibility and overall efficiency were identified as the highest-ranked success factors for blockchain implementation. Further, Paliwal et al. (2020) investigated the role of BCT in managing sustainable practices. The results from the study demonstrated traceability and transparency as the potential advantages of adopting BCT. Similarly, Ebinger and Omondi (2020) presented an overview of the digitalization of SSC transparency in SSC management. Bai and Sarkis (2020) introduced BCT performance measures integrating SSC transparency and technical attributes. The study can assist the managers and researchers in understanding the BCT selection decision.

Further, Manupati et al. (2020) developed a distributed ledger-based blockchain approach to examine supply chain performance and optimize emission levels and operational costs. The problem was formulated as a Mixed-Integer Non-Linear Programming (MINLP) model. Caldarelli et al. (2020) evaluated the effectiveness of blockchain technology for sustainability issues. The study addressed the blockchain oracle problem in the traceability of non-fungible products. Further, Sunmola (2021) presented a study of BCT concerning sustainable supply chain visibility. The study suggested a framework for blockchain-based sustainable supply chain visibility management, focusing on awareness of the context. Sahoo and Halder (2020) proposed a novel smart e-waste management system by adopting BCT and smart contracts, considering forward and reverse supply chains. The study discussed various challenges and limitations that existing blockchain solutions have been facing in e-waste management.

Similarly, Zhang et al. (2020) suggested a framework obtained from the integration of BCT, IoT, big data analytics, and visualization. The study can assist organizations in attaining operational excellence in organizing Life Cycle Assessments (LCA) for improving supply chain sustainability. Further, Yadav and Singh (2020) identified blockchain critical success factors in SSCs. The study integrated the concept of blockchain-related information technology and supply chain for operations. Rejeb and Rejeb (2020) performed a literature analysis to determine the studies specific to blockchain and supply chain sustainability. The results from the study concluded that the majority of studies focused on the economic implications of blockchains on supply chains. Sundarakani et al. (2021) studied a supply chain problem associated to cross border cargo transportation. Blockchains and big data were used to identify the key implementation guidelines and major issues faced during the supply chain network design. Marshall and Archibald (2018) investigated a problem related to PRS and proposed two recovery channels (i) recovery into components and (ii) into serviceable items. The study determined the total cost per unit period and optimal lot size.

Further, Mubarik et al. (2020) examined the role of blockchain-based sustainability on supply chain integration. The findings from the study revealed that blockchain technology has substantial capability to enhance the integration between numerous actors in multi-level supply chains. Similarly, Dindarian and Chakravarthy (2019) explored cases involving blockchain technology in the waste management industry. Parung (2019) highlighted the use of blockchain technology to support studies specific to SSCs. Further, Saberi et al. (2019) examined BCT and smart contracts with potential supply chain management. The study introduced four blockchain technology adoption barriers: inter-organizational, intra-organizational, technical, and external barriers. Further, Nayak and Dhaigude (2019)

proposed a conceptual model of SSC in small and medium enterprises adopting BCT. The study identified the antecedents of an SSC using the BCT approach.

## 2.2 Research gaps and contributions

Based on deliberated literature study, it can be seen that a number of studies have examined barriers, challenges, and issues for a PRS's successful implementation. Additionally, there are numerous articles in the literature pertinent to blockchain-based architects. However, to the best of my knowledge, no study in the literature depicts their linkage with the PRS. There is a requirement to obtain the BRCs for PRS. Therefore, the current research focuses on the above concern and enhances the latest literature by:

- Finalizing potential BRCs with the help of literature review and experts' recommendations.
- Evaluating BRCs for PRS to achieve the ranking and categorization in cause-effect group by using the fuzzy DEMATEL-MMDE approach.

## 2.3 Identification of BRCs for PRS

In developing countries, manufacturing industries search for innovative digital technologies to enhance their performance through efficient collaboration and coordination in the recovery chain (Farooq & O'Brien, 2012). In recent years, the adoption of BCT has resulted in better visibility and transparency of transactions in the recovery chains (Pilkington, 2016). In the literature, there are various readiness challenges for the successful implementation of blockchain in PRSs. Therefore, it becomes essential to study the potential BRCs for PRS. In the present study, twenty potential BRCs for PRS in the manufacturing industry were identified through a literature study and experts' recommendations. The identified BRCs for PRS are presented in Table 2.

# 3 Methodology and data analysis

This section explains the DEMATEL approach and MMDE algorithm, which are implemented to perform the data analysis and identify the potential BRCs for PRS implementation. Figure 1 shows the research framework adopted for the study with the different steps.

## 3.1 Questionnaire development and data collection

In this study, a questionnaire was arranged to accelerate data collection for the DEMATEL analysis, arresting the experts' recommendations. The questionnaire provided a detailed description of each BRC specific to PRS implementation to support the experts (Appendix 1). A total of 17 experts from different manufacturing industries in India were elected for collecting data based on adopting convenience sampling. The experts were contacted via phone calls and the web. Later, seven experts were approved to contribute to the survey. The sample size highlights the target population which is low but presumed to be satisfactory as seen in the previous studies that adopted the fuzzy DEMATEL approach (Kazancoglu et al., 2018; Khan et al., 2019; Parmar & Desai, 2020). A brief introduction of the experts and their organizations is presented in Table 3.

**Table 2** Identification of BRCs for PRS

| Code | Blockchain readiness challenges (BRCs) | Definition | Reference |
|---|---|---|---|
| BRC1 | An inadequate mechanism for BCT pursuit in the PRS | The adoption of traditional technologies impends to undercut the advantages of BCT implementation in PRS. Furthermore, the application of inappropriate mechanisms minimizes the potential benefits of BCT | Nandi et al. (2021); Zwitter and Hazenberg (2020) |
| BRC2 | Challenges in assimilating the PRS and BCT | The adoption of BCT in PRS highlights a few challenges for the organizations. Therefore, the advancement of organizational effectiveness is required to cater to the challenges and expedite the advantages of BCT for PRSs | Jabbour et al. (2020); Verhoeven et al. (2018) |
| BRC3 | Lack of customer cognizance towards the PRS and BCT | The lack of customer cognizance towards BCT for PRSs occurs because of inefficient information transfer and coordination between the participants with varying objectives | Kouhizadeh et al. (2021); Saberi et al. (2019); Mangla et al. (2018); |
| BRC4 | Infantile challenges of BCT | The infantile nature of BCT results in a threat to tackle the technical challenges for gathering the data specific to PRS in actual time. Therefore, it becomes essential to encourage BCT adoption in PRSs among manufacturing organizations | Faroque et al. (2020); Tian (2016) |
| BRC5 | High costs linked with BCT implementation | The amalgamation of BCT and PRS is time-exhausting and requires a high cost to undertake. Additionally, the integration of BCT with PRS requires an interface with tailored explanations as traditional interfaces are not in existence presently | Prewett et al. (2020); Khatoon et al. (2019) |

**Table 2** (continued)

| Code | Blockchain readiness challenges (BRCs) | Definition | Reference |
|---|---|---|---|
| BRC6 | Reluctant to convert to a new arrangement | Organizations are reluctant to implement inter-organizational technology regardless of the advantages of BCT. One reason for the same can be seen concerning different objectives and significance of the organizations | Dwivedi et al., (2021a); Bai and Sarkis (2020); Saberi et al. (2019) |
| BRC7 | Lack of organizational policies and frameworks for BCT adoption | In the literature, some studies have measured some facilitating circumstances in their assessment frameworks regarding BCT adoption. There is a lack of a framework and organizational policies for BCT adoption in PRS | Balasubramanian et al. (2021); Clohessy and Acton (2019) |
| BRC8 | Inadequate financing for PRS exercises | The organizations require adequate finances to evaluate the customers and suppliers for the smooth implementation of PRS practices. A lack of finances results in a risk to the recovery chain partners | Lampón et al. (2021); Leng and Zailani (2012) |
| BRC9 | Inadequate organizational structures to support PRS | Various factors might resist the PRS drivers from implementing the BCT practices. There is a requirement for top management commitment and efficient organizational structure for the smooth functioning of the PRS | Heiss et al. (2019); Fawcett et al. (2006) |
| BRC10 | Lack of IT arrangements to assist PRS | Effectual IT arrangements are required for tracking the returned products. Therefore, a lack of IT arrangements is a problematic obstruction faced by the organizations functional in implementing PRS | Cannella et al. (2016); Jayaraman et al. (2008); |
| BRC11 | Security challenges to BCT implementation | BCT is known for security features with a distributed nature that eventually contributes to more safety. However, the major challenge in PRS implementation is the privacy and security of keeping records for the movement of products | Khan et al. (2020); Rane and Narvel (2019) |

**Table 2** (continued)

| Code | Blockchain readiness challenges (BRCs) | Definition | Reference |
|---|---|---|---|
| BRC12 | Lack of technological maturity towards PRSs | A lack of expertise regarding the implementation of digital technologies is considered an essential blockade in the implementation of PRS | Oliveira et al. (2019); Bag et al. (2020) |
| BRC13 | Inadequate standards for PRS operations | A lack of knowledge and information regarding the inadequate standards for PRS operations is an important blockade to occupy BCT adoption | Dasaklis et al. (2020); Al Zaabi et al. (2013) |
| BRC14 | Market impediments and uncertainty | In manufacturing industries, the market impediments and uncertainty are dealt with in a specific representation of a network. Therefore, by sharing information with customers, manufacturers can decrease the demand uncertainty and efficiently plan the supply chain movements | Ho et al. (2005); Bag et al. (2020); Pratap et al., (2021) |
| BRC15 | Traceability and visibility concerns with BCT adoption | BCT contributes to substantial improvements in visibility and traceability by maintaining information regularity across the recovery chain partners. Therefore, traceability refers to be a blockade in adopting BCT for PRSs | Kamble et al. (2021); Yadav and Singh (2020) |
| BRC16 | Limited scalability with BCT's implementation in PRS | There is a requirement for a scalable framework that allows the partners within an organization to select nodes in accomplishing consensus and mitigating partiality to cater to the complexities concerning inconsistency and consensus partiality | Dasaklis et al. (2020); Viriyasitavat and Hoonsopon (2019) |
| BRC17 | Lack of awareness and expertise towards BCT adoption | A lack of expertise among employees towards BCT adoption is considered a major hurdle towards its implementation in the PRS. There are requirements for the arrangement of training and sessions for an effective understanding of BCT adoption | Rana et al. (2021); Saberi et al. (2019) |

**Table 2** (continued)

| Code | Blockchain readiness challenges (BRCs) | Definition | Reference |
|---|---|---|---|
| BRC18 | Data processing and storage challenges with BCT in PRS | BCT adopts innovative technologies in the appearance of distributed data processing and storage, decentralized and centralized transactions, and encryption procedures. Still, data processing and storage can be seen as a threat to BCT adoption in PRS | Lu (2019); Dinh et al. (2018) |
| BRC19 | Privacy challenges with BCT | Previous studies highlight the privacy challenges with BCT adoption from the perspective of transaction-specific privacy and consumers' privacy | Feng et al. (2019); Mohanta et al. (2019) |
| BRC20 | Lack of governance and standards | A lack of government policies and standards can be viewed as a potential blockade to BCT implementation in PRS | Dwivedi et al. (2021b); Yadav et al. (2020); Zachariadis et al. (2019) |
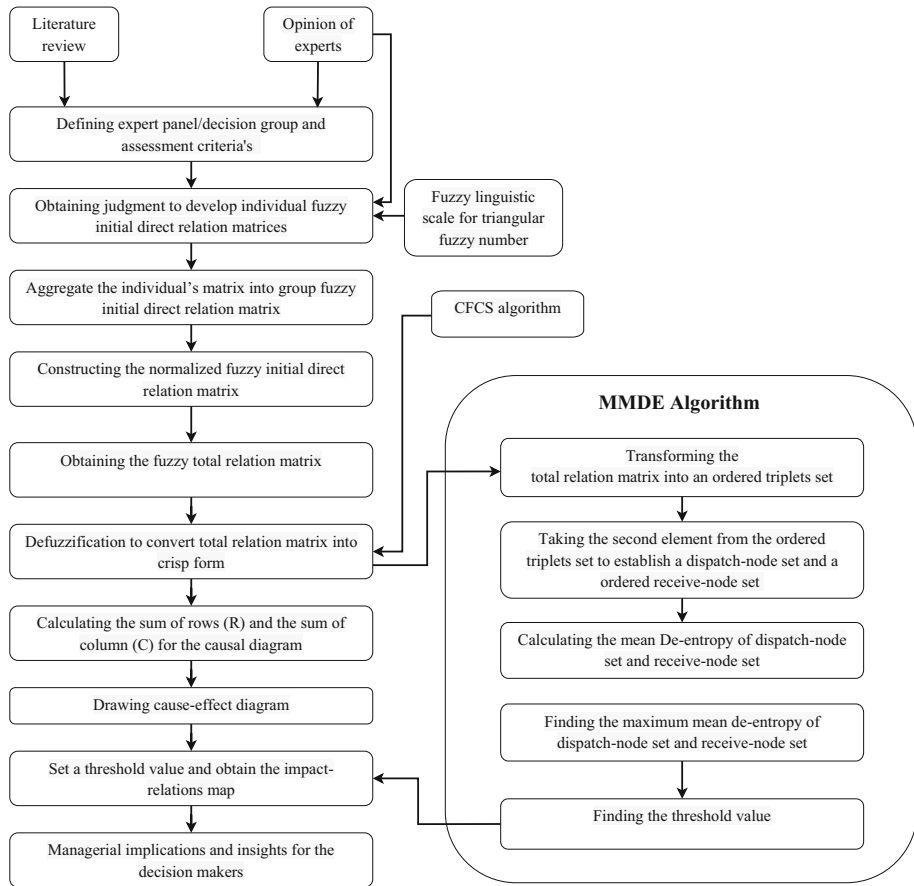
**Fig. 1** Research framework for the Study

**Table 3** Introduction of decision-makers (DMs) with their organization

| Decision-maker | Designation | Years of experience | Organization |
|---|---|---|---|
| DM 1 | Supply Chain Manager | 13 years | Electronics goods industry |
| DM 2 | Executive Engineer | 18 years | Electronics goods industry |
| DM 3 | Production Manager | 11 years | Automobile industry |
| DM 4 | Policy Maker | 21 years | Government |
| DM 5 | General manager | 15 years | Automobile industry |
| DM 6 | Managing Director | 17 years | Leather industry |
| DM 7 | Production Manager | 13 years | Leather industry |

**Table 4** Linguistic scale for fuzzy DEMATEL

| Linguistic variable | Triangular fuzzy numbers |
|---|---|
| No influence (No) | (0, 0, 0.25) |
| Very low influence (VL) | (0, 0.25, 0.50) |
| Low influence (L) | (0.25, 0.50, 0.75) |
| High influence (H) | (0.50, 0.75, 1.0) |
| Very high influence (VH) | (0.75, 1.0, 1.0) |

The electronic goods industry is selected for the survey since recycling and recovery of products adopted in the electronic goods can be employed as secondary raw material in other arrangements. BCT has the potential to track the products in a secure cloud system that makes the industry a more apparent and safer place (Lee & Pilkington, 2017). Also, experts from leather industry are elected for the survey. The leather industry is one of the most polluted manufacturing industries. Thus, there is a requirement to assess the environmental sustainability in the leather supply chain. The application of BCT allows traceability from raw material to final manufactured product. Also, supply chain traceability refers to improved environmental sustainability (Marconi et al., 2017). Further, BCT adoption encourages enhanced coordination among the different stakeholders (Karuppiah et al., 2021). In the automobile industry, value is created through transactions and contracts in business networks that construct a flow of products and services (Kamble et al., 2021). BCT provides organizations with increased supply chain visibility and transparency in transactions (Ivanov et al., 2019). Therefore, experts from the automobile industry are included in the survey analysis. The DMs adopted a set of fuzzy numbers and fuzzy membership functions to judge the potential BRCs in Table 4. The pairwise comparison was prepared for a single decision-maker adopting the linguistic variables.

### 3.2 Fuzzy DEMATEL methodology

The DEMATEL method was advanced in 1973 by the Battelle Memorial Institute through the Geneva Research Centre. The DEMATEL methodology was employed to interpret the interactions among the complex criteria. DEMATEL is an MCDM approach that handles the decision-making problem and associates it with other methodologies to generate more acceptable results for the problem (Lee and Lin, 2013). Human decisions have ambiguity and vagueness in their criteria. The implementation of the fuzzy set theory in the DEMATEL technique prevents incomplete and inaccurate information from being featured in human decisions (Bhatia and Srivastava, 2018). Therefore, integrating the fuzzy logic during the data collection could be a solution to cater this problem. However, the DEMATEL results contain redundant information, challenging researchers to analyze their research problems (Li & Tzeng, 2009). Therefore, the MMDE algorithm is combined with DEMATEL to determine the threshold values to identify the BRCs for PRS, which can shorten the quantity of information with the concept of entropy. In past studies, the combined fuzzy DEMATEL-MMDE methodology is employed by the researchers, such as barriers of IoT's implementation in the manufacturing industry (Singh & Bhanot, 2020), identifying the best design criteria for an individual product (Younesi and Roghanian, 2015), ranking the financial ratios in shipping companies (Lee and Lin, 2013), and the like.

The present study adopted the fuzzy DEMATEL method to increase the accuracy of the analysis. The recommendations of the industry professionals and academicians were obtained through a questionnaire, where the BRCs for PRS were arranged to adopt a fuzzy linguistic range in Table 4.

The steps for the fuzzy DEMATEL approach are presented as follows.

### 3.2.1 Building of average direct relation matrix

In this step, a fuzzy linguistic scale was adopted to discover the interactions among the *i-j* $^{th}$ factor, as highlighted in Table 4. Further, the fuzzy triangular numbers and aggregate the fuzzy numbers were consigned. De-fuzzification was performed by transforming the fuzzy data into crisp scores (CFCS) (Opricovic & Tzeng, 2003).

Let, $\widetilde{A_{ij}^n} = (a_{ij}^n, b_{ij}^n, c_{ij}^n)$, and influence matrix is determined as,

$$\tilde{A}^n = \begin{bmatrix} 0\tilde{A}_{12}^n\tilde{A}_{13}^n \dots \tilde{A}_{1m}^n \\ \tilde{A}_{21}^n 0\tilde{A}_{23}^n \dots \tilde{A}_{2m}^n \\ \dots \\ \dots \\ \tilde{A}_{m1}^n \tilde{A}_{m2}^n \tilde{A}_{m3}^n \dots 0 \end{bmatrix}, \ n = 1, 2, 3 \dots, h, \tag{1}$$

where $m$ is the number of criteria, and $h$ is the number of experts.

The step-wise algorithm of the CFCS process is presented as:

Normalization:

$$xc_{ij}^n = \left(c_{ij}^n - \min a_{ij}^n\right)/\Delta_{\min}^{\max} \tag{2}$$

$$xb_{ij}^n = \left(b_{ij}^n - \min a_{ij}^n\right)/\Delta_{\min}^{\max} \tag{3}$$

$$xa_{ij}^n = \left(a_{ij}^n - \min a_{ij}^n\right)/\Delta_{\min}^{\max} \tag{4}$$

where $\Delta_{\min}^{\max} = \max c_{ij}^n - \min a_{ij}^n$.

Determine the right-side and left side normalized values:

$$xcs_{ij}^n = \frac{xc_{ij}^n}{\left(1 + xc_{ij}^n - xb_{ij}^n\right)}. \tag{5}$$

$$xas_{ij}^n = \frac{xb_{ij}^n}{\left(1 + xb_{ij}^n - xa_{ij}^n\right)} \tag{6}$$

Determine the total normalized crisp values:

$$x_{ij}^n = \left[xas_{ij}^n\left(1 - xas_{ij}^n\right) + xcs_{ij}^n \times xcs_{ij}^n\right]/1 - xcs_{ij}^n \times xcs_{ij}^n + xcs_{ij}^n \tag{7}$$

Determine the crisp values:

$$z_{ij}^n = \min a_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max} \tag{8}$$

Relate the crisp values:

$$z_{ij} = \frac{1}{h}\left(z_{ij}^1 + z_{ij}^2 - - - -z_{ij}^h\right) \tag{9}$$

**Table 5** Group direct-influence fuzzy matrix

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 | BRC11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BRC1 | | H | VL | L | VH | L | VH | VH | VH | VH | VH |
| BRC2 | VH | | No | H | H | VH | VH | H | H | VH | L |
| BRC3 | L | No | | No | No | L | H | H | L | L | No |
| BRC4 | No | No | No | | VH | VH | H | VL | No | VH | VL |
| BRC5 | VH | L | VL | L | | H | No | H | No | VH | No |
| BRC6 | VL | No | L | L | L | | No | H | VH | VH | L |
| BRC7 | VH | H | H | H | No | No | | L | VH | L | H |
| BRC8 | VH | L | No | H | L | H | VH | | H | H | VH |
| BRC9 | VH | H | L | No | L | L | H | H | | VL | L |
| BRC10 | VH | H | VL | No | L | H | L | H | H | | No |
| BRC11 | L | H | No | VH | H | VH | H | L | VH | VH | |
| BRC12 | H | VH | No | H | | H | H | VH | H | VH | No |
| BRC13 | H | H | L | VH | H | H | VH | H | H | H | L |
| BRC14 | L | H | No | H | H | L | H | L | VH | L | VH |
| BRC15 | L | H | VL | H | L | VH | VL | H | H | H | No |

**Table 5** (continued)

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 | BRC11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BRC16 | No | L | No | VL | H | H | VL | VL | L | H | No |
| BRC17 | H | H | VH | L | VH | H | VH | H | H | H | H |
| BRC18 | L | H | No | No | H | VL | L | L | L | H | H |
| BRC19 | L | H | VL | No | L | L | L | L | L | H | H |
| BRC20 | H | H | L | L | H | VH | H | H | H | H | H |

| BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|
| H | VH | L | VH | L | H | L | VH | VH |
| L | H | H | VL | No | VL | VL | L | H |
| No | L | H | VL | No | L | No | L | VL |
| H | L | L | VH | VL | H | VL | No | VL |
| No | H | No | L | No | VL | H | VL | VH |
| No | VH | No | VH | No | L | VL | VL | VH |
| H | H | VH | L | VL | L | L | L | VH |
| H | VH | H | L | H | H | L | L | H |
| L | L | H | No | No | H | H | H | VH |
| VH | VH | H | H | VH | VL | VH | VH | H |
| L | H | L | H | H | VL | VH | VH | H |
| | H | | L | VH | VL | H | VH | VH |

**Table 5** (continued)

| BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|
| L |  | H | L | VH | H | H | H | H |
| H | H | No | No | No | L | No | No | H |
| VL | L |  |  | H | VL | H | VH | L |
| H | H | L | L |  | VL | H | L | L |
| H | H | L | L | VL |  | H | H | VH |
| L | L | L | H | L | No |  | H | H |
| L | L | VL | H | No | L | L |  | L |
| L | VH | L | No | No | H | L | H |  |

As shown in Eq. (10), the group direct-influence fuzzy matrix was obtained by assigning the linguistic variables for each identified BRC to PRS in Table 5.

$$Z = [z_{ij}] \tag{10}$$

### 3.2.2 Normalization of direct relation matrix

The normalized direct-influence fuzzy matrix $X$ was attained using Eq. (11), and data are presented in above Table 6.

$$X = \lambda * Z, \tag{11}$$

where

$$\lambda = \min \left[ \frac{1}{\max 1 \le i \le m \sum_{j=1}^{m} |z_{ij}|} ; \frac{1}{\max 1 \le j \le m \sum_{i=1}^{m} |z_{ij}|} \right]$$

### 3.2.3 Determination of total relation matrix

$$T = X(I - X)^{-1}, \tag{12}$$

where I is the identity matrix, and X is the normalized direct-influence fuzzy matrix.

The fuzzy total relation matrix and defuzzified total relation matrix are presented in Tables 7 and 8. In the defuzzified total relation matrix in Table 8, the sum of rows (D) and columns (R) are obtained as:

$$T = [t_{ij}] \, m \times m, \ i, \ j = 1, \ 2, \ldots, m, \tag{13}$$

$$D = \left[ \sum_{j=1}^{m} t_{ij} \right] m \times 1 = [t_i]m \times 1 \tag{14}$$

$$R = \left[ \sum_{i=1}^{m} t_{ij} \right] 1 \times m = [t_j]1 \times m \tag{15}$$

Later, D and R values were added and subtracted to attain the values of prominence (D + R) and influence (D-R).

### 3.2.4 Preparation of cause-and-effect diagram

The cause-and-effect diagram highlighted the cause and effects for the BRCs for PRS. They were developed in this step using the (D + R) and (D-R) values.

### 3.3 Maximum mean de-entropy (MMDE) algorithm

In the DEMATEL methodology, the experts' recommendations were employed to find the threshold values. The determination of a logical threshold value was a tedious task. Therefore, the MMDE algorithm was suggested to obtain a threshold value for plotting the impact-relations map (Li & Tzeng, 2009). The various steps used in the MMDE algorithm are highlighted as follows (Chen and Li, 2012):

**Table 6** Normalized direct-influence fuzzy matrix

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 | BRC11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BRC1 | (0, 0, 0) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) |
| BRC2 | (0.042, 0.056, 0.056) | (0, 0, 0) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) |
| BRC3 | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0, 0, 0) | (0, 0, 0.014) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0, 0, 0.014) |
| BRC4 | (0, 0, 0.014) | (0, 0, 0.014) | (0, 0, 0.014) | (0, 0, 0) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0, 0, 0.014) | (0.042, 0.056, 0.056) | (0, 0.014, 0.028) |
| BRC5 | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.042, 0.056, 0.056) | (0, 0, 0.014) |
| BRC6 | (0, 0.014, 0.028) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0, 0, 0) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) |
| BRC7 | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0, 0, 0.014) | (0, 0, 0) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) |
| BRC8 | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) |
| BRC9 | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) |

**Table 6** (continued)

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 | BRC11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BRC10 | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0) | (0, 0, 0.014) |
| BRC11 | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0, 0, 0) |
| BRC12 | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0.014) |
| BRC13 | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) |
| BRC14 | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) |
| BRC15 | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0.014) |
| BRC16 | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0, 0.014) |
| BRC17 | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) |
| BRC18 | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) |

**Table 6** (continued)

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 | BRC11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BRC19 | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) |
| BRC20 | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) |

| Code | BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|---|
| BRC12 | | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) |
| BRC13 | (0.028, 0.042, 0.056) | | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0, 0, 0.014) | (0, 0.014, 0.028) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) |
| BRC14 | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | | (0, 0.014, 0.028) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0, 0.014, 0.028) |
| BRC15 | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0, 0, 0.014) | (0, 0.014, 0.028) |
| BRC16 | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.042, 0.056, 0.056) |
| BRC17 | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | | (0, 0.014, 0.028) | (0, 0.014, 0.028) | (0.042, 0.056, 0.056) |
| BRC18 | (0, 0, 0.014) | (0.042, 0.056, 0.056) | (0, 0, 0.014) | (0.042, 0.056, 0.056) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) |
| BRC19 | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | | (0.028, 0.042, 0.056) |
| BRC20 | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | |

**Table 6** (continued)

| BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|
| (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) |
| (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0, 0.014, 0.028) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) |
| (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) |
| (0, 0, 0) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.042, 0.056, 0.056) |
| (0.014, 0.028, 0.042) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) |
| (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0, 0, 0) | (0, 0, 0.014) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0, 0, 0.014) | (0.028, 0.042, 0.056) |
| (0, 0.014, 0.028) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) |
| (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0, 0, 0) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) |
| (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0, 0.014, 0.028) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) | (0.042, 0.056, 0.056) |
| (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0, 0, 0) | (0.028, 0.042, 0.056) | (0.028, 0.042, 0.056) |
| (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0, 0.014, 0.028) | (0.028, 0.042, 0.056) | (0, 0, 0.014) | (0.014, 0.028, 0.042) | (0.014, 0.028, 0.042) | (0, 0, 0) | (0.014, 0.028, 0.042) |
| (0.014, 0.028, 0.042) | (0.042, 0.056, 0.056) | (0.014, 0.028, 0.042) | (0, 0, 0.014) | (0, 0, 0.014) | (0.028, 0.042, 0.056) | (0.014, 0.028, 0.042) | (0.028, 0.042, 0.056) | (0, 0, 0) |

**Table 7** Fuzzy total relation matrix

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 |
|---|---|---|---|---|---|---|---|---|---|---|
| BRC1 | (0.025, 0.082, 0.257) | (0.049, 0.116, 0.317) | (0.007, 0.048, 0.187) | (0.031, 0.087, 0.263) | (0.06, 0.124, 0.298) | (0.038, 0.109, 0.307) | (0.062, 0.13, 0.308) | (0.062, 0.132, 0.326) | (0.065, 0.136, 0.322) | (0.067, 0.143, 0.339) |
| BRC2 | (0.058, 0.117, 0.281) | (0.015, 0.058, 0.234) | (0.005, 0.027, 0.156) | (0.039, 0.087, 0.251) | (0.041, 0.096, 0.271) | (0.057, 0.115, 0.29) | (0.057, 0.113, 0.28) | (0.043, 0.102, 0.295) | (0.046, 0.105, 0.292) | (0.059, 0.124, 0.307) |
| BRC3 | (0.022, 0.063, 0.208) | (0.007, 0.033, 0.186) | (0.003, 0.016, 0.106) | (0.006, 0.026, 0.159) | (0.006, 0.03, 0.174) | (0.02, 0.06, 0.213) | (0.035, 0.075, 0.22) | (0.034, 0.075, 0.231) | (0.023, 0.065, 0.217) | (0.021, 0.064, 0.226) |
| BRC4 | (0.012, 0.046, 0.197) | (0.01, 0.042, 0.202) | (0.004, 0.021, 0.129) | (0.008, 0.035, 0.16) | (0.049, 0.092, 0.227) | (0.052, 0.099, 0.244) | (0.035, 0.08, 0.233) | (0.011, 0.059, 0.222) | (0.012, 0.047, 0.207) | (0.054, 0.105, 0.257) |
| BRC5 | (0.052, 0.099, 0.237) | (0.024, 0.068, 0.228) | (0.003, 0.033, 0.142) | (0.021, 0.06, 0.199) | (0.011, 0.042, 0.178) | (0.039, 0.087, 0.245) | (0.012, 0.044, 0.197) | (0.039, 0.086, 0.25) | (0.013, 0.047, 0.208) | (0.055, 0.106, 0.26) |
| BRC6 | (0.014, 0.063, 0.215) | (0.012, 0.045, 0.207) | (0.018, 0.049, 0.158) | (0.022, 0.062, 0.202) | (0.024, 0.071, 0.221) | (0.014, 0.051, 0.197) | (0.012, 0.048, 0.202) | (0.039, 0.089, 0.254) | (0.053, 0.103, 0.25) | (0.054, 0.107, 0.262) |
| BRC7 | (0.058, 0.116, 0.284) | (0.043, 0.1, 0.291) | (0.032, 0.066, 0.196) | (0.04, 0.087, 0.254) | (0.015, 0.058, 0.236) | (0.017, 0.065, 0.256) | (0.019, 0.065, 0.234) | (0.03, 0.09, 0.287) | (0.059, 0.12, 0.297) | (0.032, 0.097, 0.298) |
| BRC8 | (0.06, 0.124, 0.305) | (0.032, 0.094, 0.3) | (0.006, 0.031, 0.172) | (0.042, 0.095, 0.273) | (0.032, 0.092, 0.283) | (0.047, 0.112, 0.316) | (0.06, 0.123, 0.305) | (0.018, 0.071, 0.269) | (0.049, 0.115, 0.319) | (0.05, 0.121, 0.335) |
| BRC9 | (0.056, 0.112, 0.276) | (0.041, 0.094, 0.281) | (0.018, 0.052, 0.178) | (0.011, 0.043, 0.207) | (0.027, 0.078, 0.252) | (0.028, 0.083, 0.269) | (0.043, 0.098, 0.275) | (0.042, 0.098, 0.289) | (0.017, 0.061, 0.234) | (0.017, 0.078, 0.274) |

**Table 7** (continued)

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 |
|---|---|---|---|---|---|---|---|---|---|---|
| BRC10 | (0.059, 0.12, 0.29) | (0.045, 0.104, 0.297) | (0.004, 0.041, 0.174) | (0.013, 0.05, 0.22) | (0.03, 0.087, 0.267) | (0.045, 0.107, 0.299) | (0.031, 0.091, 0.276) | (0.045, 0.108, 0.306) | (0.047, 0.11, 0.303) | (0.021, 0.076, 0.265) |
| BRC11 | (0.033, 0.097, 0.289) | (0.045, 0.106, 0.31) | (0.005, 0.029, 0.169) | (0.053, 0.105, 0.269) | (0.044, 0.105, 0.293) | (0.06, 0.125, 0.313) | (0.044, 0.107, 0.301) | (0.031, 0.097, 0.306) | (0.061, 0.126, 0.315) | (0.063, 0.134, 0.332) |
| BRC12 | (0.045, 0.104, 0.283) | (0.057, 0.114, 0.29) | (0.004, 0.027, 0.158) | (0.039, 0.087, 0.253) | (0.016, 0.059, 0.224) | (0.045, 0.106, 0.293) | (0.045, 0.103, 0.284) | (0.057, 0.117, 0.298) | (0.046, 0.108, 0.297) | (0.048, 0.113, 0.311) |
| BRC13 | (0.047, 0.112, 0.316) | (0.045, 0.107, 0.323) | (0.019, 0.057, 0.204) | (0.054, 0.106, 0.281) | (0.045, 0.106, 0.306) | (0.047, 0.113, 0.327) | (0.059, 0.123, 0.316) | (0.045, 0.111, 0.334) | (0.048, 0.115, 0.33) | (0.05, 0.122, 0.348) |
| BRC14 | (0.029, 0.083, 0.252) | (0.041, 0.09, 0.269) | (0.004, 0.023, 0.146) | (0.039, 0.083, 0.238) | (0.04, 0.088, 0.255) | (0.029, 0.082, 0.26) | (0.042, 0.094, 0.265) | (0.027, 0.081, 0.265) | (0.056, 0.109, 0.275) | (0.03, 0.088, 0.276) |
| BRC15 | (0.026, 0.079, 0.252) | (0.038, 0.088, 0.27) | (0.003, 0.035, 0.159) | (0.034, 0.077, 0.236) | (0.025, 0.075, 0.245) | (0.054, 0.107, 0.275) | (0.011, 0.063, 0.239) | (0.038, 0.092, 0.28) | (0.04, 0.093, 0.276) | (0.043, 0.101, 0.291) |
| BRC16 | (0.01, 0.046, 0.21) | (0.023, 0.069, 0.241) | (0.002, 0.019, 0.136) | (0.007, 0.046, 0.196) | (0.035, 0.079, 0.24) | (0.037, 0.085, 0.257) | (0.008, 0.055, 0.221) | (0.01, 0.058, 0.236) | (0.024, 0.072, 0.246) | (0.039, 0.09, 0.272) |
| BRC17 | (0.048, 0.115, 0.315) | (0.046, 0.108, 0.321) | (0.047, 0.085, 0.216) | (0.028, 0.081, 0.266) | (0.057, 0.117, 0.303) | (0.047, 0.114, 0.325) | (0.06, 0.124, 0.314) | (0.047, 0.114, 0.332) | (0.049, 0.116, 0.328) | (0.05, 0.123, 0.345) |
| BRC18 | (0.027, 0.079, 0.254) | (0.039, 0.089, 0.273) | (0.002, 0.02, 0.146) | (0.009, 0.039, 0.199) | (0.038, 0.085, 0.257) | (0.013, 0.066, 0.249) | (0.025, 0.075, 0.252) | (0.025, 0.078, 0.267) | (0.027, 0.08, 0.265) | (0.042, 0.098, 0.291) |

**Table 7** (continued)

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 |
|---|---|---|---|---|---|---|---|---|---|---|
| BRC19 | (0.025, 0.078, 0.248) | (0.038, 0.087, 0.267) | (0.003, 0.034, 0.156) | (0.008, 0.038, 0.194) | (0.023, 0.07, 0.238) | (0.025, 0.077, 0.256) | (0.024, 0.075, 0.247) | (0.025, 0.077, 0.262) | (0.026, 0.079, 0.259) | (0.04, 0.096, 0.284) |
| BRC20 | (0.045, 0.106, 0.296) | (0.043, 0.099, 0.301) | (0.019, 0.055, 0.191) | (0.026, 0.075, 0.25) | (0.042, 0.097, 0.284) | (0.058, 0.118, 0.304) | (0.045, 0.103, 0.295) | (0.044, 0.105, 0.311) | (0.046, 0.107, 0.307) | (0.047, 0.113, 0.323) |

| Code | BRC11 | BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|---|---|
| BRC11 | (0.057, 0.112, 0.27) | (0.044, 0.104, 0.291) | (0.066, 0.142, 0.336) | (0.031, 0.09, 0.276) | (0.057, 0.116, 0.281) | (0.027, 0.074, 0.223) | (0.039, 0.097, 0.275) | (0.033, 0.096, 0.283) | (0.062, 0.129, 0.303) | (0.068, 0.144, 0.335) |
| BRC12 | (0.026, 0.075, 0.234) | (0.027, 0.078, 0.251) | (0.047, 0.111, 0.305) | (0.04, 0.09, 0.263) | (0.013, 0.064, 0.229) | (0.009, 0.036, 0.176) | (0.01, 0.06, 0.226) | (0.012, 0.066, 0.242) | (0.028, 0.084, 0.26) | (0.047, 0.112, 0.304) |
| BRC13 | (0.007, 0.029, 0.158) | (0.006, 0.029, 0.17) | (0.022, 0.066, 0.225) | (0.033, 0.069, 0.208) | (0.005, 0.04, 0.175) | (0.004, 0.02, 0.132) | (0.019, 0.053, 0.187) | (0.005, 0.029, 0.171) | (0.02, 0.059, 0.202) | (0.009, 0.054, 0.212) |
| BRC14 | (0.006, 0.044, 0.18) | (0.035, 0.075, 0.222) | (0.027, 0.078, 0.243) | (0.02, 0.06, 0.207) | (0.05, 0.09, 0.216) | (0.007, 0.042, 0.158) | (0.032, 0.071, 0.211) | (0.009, 0.053, 0.201) | (0.01, 0.043, 0.192) | (0.014, 0.066, 0.229) |
| BRC15 | (0.009, 0.035, 0.171) | (0.009, 0.037, 0.184) | (0.042, 0.092, 0.256) | (0.008, 0.035, 0.183) | (0.023, 0.065, 0.205) | (0.008, 0.028, 0.146) | (0.007, 0.047, 0.188) | (0.036, 0.078, 0.226) | (0.012, 0.057, 0.207) | (0.054, 0.104, 0.256) |
| BRC16 | (0.021, 0.062, 0.198) | (0.009, 0.039, 0.187) | (0.055, 0.107, 0.26) | (0.009, 0.039, 0.187) | (0.049, 0.091, 0.22) | (0.008, 0.03, 0.148) | (0.021, 0.063, 0.204) | (0.011, 0.057, 0.205) | (0.013, 0.061, 0.211) | (0.054, 0.107, 0.259) |

**Table 7** (continued)

| BRC11 | BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|---|
| (0.04, 0.089, 0.25) | (0.04, 0.092, 0.269) | (0.046, 0.11, 0.308) | (0.054, 0.106, 0.268) | (0.025, 0.075, 0.245) | (0.009, 0.05, 0.192) | (0.024, 0.073, 0.242) | (0.026, 0.079, 0.258) | (0.03, 0.087, 0.266) | (0.06, 0.124, 0.307) |
| (0.055, 0.107, 0.267) | (0.043, 0.099, 0.288) | (0.063, 0.133, 0.333) | (0.042, 0.097, 0.286) | (0.029, 0.084, 0.265) | (0.038, 0.082, 0.233) | (0.038, 0.091, 0.273) | (0.029, 0.089, 0.279) | (0.032, 0.094, 0.286) | (0.051, 0.122, 0.332) |
| (0.027, 0.074, 0.231) | (0.025, 0.073, 0.245) | (0.031, 0.091, 0.285) | (0.038, 0.086, 0.258) | (0.01, 0.044, 0.21) | (0.007, 0.031, 0.17) | (0.036, 0.082, 0.246) | (0.037, 0.087, 0.261) | (0.04, 0.094, 0.268) | (0.059, 0.12, 0.297) |
| (0.014, 0.052, 0.216) | (0.054, 0.107, 0.272) | (0.062, 0.128, 0.315) | (0.04, 0.092, 0.271) | (0.041, 0.093, 0.262) | (0.052, 0.093, 0.221) | (0.01, 0.061, 0.233) | (0.055, 0.11, 0.276) | (0.058, 0.117, 0.284) | (0.049, 0.117, 0.314) |
| (0.013, 0.053, 0.212) | (0.028, 0.084, 0.272) | (0.049, 0.119, 0.329) | (0.041, 0.095, 0.282) | (0.043, 0.097, 0.275) | (0.037, 0.08, 0.23) | (0.011, 0.064, 0.244) | (0.055, 0.114, 0.289) | (0.058, 0.119, 0.295) | (0.05, 0.121, 0.328) |
| (0.014, 0.051, 0.212) | (0.014, 0.054, 0.216) | (0.048, 0.113, 0.308) | (0.027, 0.079, 0.254) | (0.027, 0.078, 0.245) | (0.05, 0.09, 0.217) | (0.011, 0.061, 0.229) | (0.04, 0.094, 0.27) | (0.056, 0.114, 0.278) | (0.061, 0.126, 0.307) |
| (0.028, 0.081, 0.264) | (0.029, 0.086, 0.285) | (0.023, 0.081, 0.292) | (0.042, 0.098, 0.296) | (0.029, 0.085, 0.275) | (0.05, 0.094, 0.239) | (0.038, 0.092, 0.282) | (0.042, 0.101, 0.301) | (0.044, 0.107, 0.309) | (0.05, 0.123, 0.343) |
| (0.051, 0.094, 0.232) | (0.038, 0.084, 0.249) | (0.043, 0.1, 0.287) | (0.011, 0.044, 0.196) | (0.01, 0.042, 0.201) | (0.008, 0.031, 0.164) | (0.022, 0.066, 0.225) | (0.012, 0.047, 0.214) | (0.013, 0.051, 0.219) | (0.045, 0.103, 0.286) |
| (0.009, 0.039, 0.194) | (0.009, 0.056, 0.225) | (0.028, 0.086, 0.275) | (0.008, 0.041, 0.21) | (0.011, 0.044, 0.19) | (0.034, 0.07, 0.204) | (0.007, 0.052, 0.212) | (0.036, 0.085, 0.254) | (0.051, 0.102, 0.26) | (0.028, 0.087, 0.274) |

**Table 7** (continued)

| BRC11 | BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|---|
| (0.006, 0.032, 0.179) | (0.034, 0.075, 0.233) | (0.038, 0.09, 0.269) | (0.02, 0.061, 0.219) | (0.021, 0.062, 0.214) | (0.006, 0.026, 0.139) | (0.004, 0.044, 0.196) | (0.035, 0.078, 0.238) | (0.023, 0.068, 0.23) | (0.026, 0.078, 0.256) |
| (0.042, 0.095, 0.275) | (0.041, 0.098, 0.295) | (0.05, 0.122, 0.342) | (0.029, 0.086, 0.282) | (0.028, 0.084, 0.273) | (0.01, 0.055, 0.213) | (0.011, 0.052, 0.227) | (0.042, 0.101, 0.299) | (0.045, 0.109, 0.308) | (0.064, 0.137, 0.341) |
| (0.036, 0.078, 0.233) | (0.022, 0.068, 0.237) | (0.028, 0.084, 0.276) | (0.022, 0.067, 0.236) | (0.036, 0.08, 0.242) | (0.021, 0.057, 0.192) | (0.006, 0.036, 0.198) | (0.01, 0.045, 0.202) | (0.039, 0.089, 0.261) | (0.041, 0.098, 0.288) |
| (0.035, 0.077, 0.229) | (0.021, 0.066, 0.231) | (0.026, 0.082, 0.269) | (0.008, 0.053, 0.218) | (0.035, 0.079, 0.237) | (0.007, 0.03, 0.162) | (0.019, 0.061, 0.219) | (0.023, 0.07, 0.236) | (0.011, 0.048, 0.203) | (0.027, 0.084, 0.269) |
| (0.04, 0.09, 0.26) | (0.026, 0.078, 0.264) | (0.061, 0.125, 0.321) | (0.027, 0.079, 0.264) | (0.013, 0.052, 0.23) | (0.009, 0.037, 0.185) | (0.037, 0.087, 0.264) | (0.027, 0.081, 0.268) | (0.043, 0.1, 0.288) | (0.021, 0.075, 0.267) |

**Table 8** De-fuzzified total relation matrix

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 |
|---|---|---|---|---|---|---|---|---|---|---|
| BRC1 | 0.1278 | 0.1625 | 0.0895 | 0.1331 | 0.1661 | 0.1549 | 0.1719 | 0.1761 | 0.1778 | 0.1848 |
| BRC2 | 0.1587 | 0.1062 | 0.0677 | 0.1324 | 0.1415 | 0.1592 | 0.1563 | 0.1500 | 0.1518 | 0.1673 |
| BRC3 | 0.1057 | 0.0783 | 0.0488 | 0.0676 | 0.0739 | 0.1045 | 0.1178 | 0.1197 | 0.1090 | 0.1100 |
| BRC4 | 0.0905 | 0.0887 | 0.0569 | 0.0747 | 0.1324 | 0.1405 | 0.1238 | 0.1049 | 0.0934 | 0.1465 |
| BRC5 | 0.1389 | 0.1133 | 0.0690 | 0.1019 | 0.0841 | 0.1310 | 0.0895 | 0.1313 | 0.0939 | 0.1478 |
| BRC6 | 0.1068 | 0.0920 | 0.0856 | 0.1041 | 0.1139 | 0.0945 | 0.0928 | 0.1340 | 0.1439 | 0.1491 |
| BRC7 | 0.1591 | 0.1477 | 0.1068 | 0.1330 | 0.1067 | 0.1155 | 0.1116 | 0.1390 | 0.1633 | 0.1457 |
| BRC8 | 0.1672 | 0.1442 | 0.0738 | 0.1414 | 0.1397 | 0.1601 | 0.1666 | 0.1217 | 0.1625 | 0.1686 |
| BRC9 | 0.1548 | 0.1423 | 0.0919 | 0.0905 | 0.1248 | 0.1314 | 0.1437 | 0.1459 | 0.1088 | 0.1277 |
| BRC10 | 0.1625 | 0.1518 | 0.0818 | 0.0979 | 0.1334 | 0.1539 | 0.1382 | 0.1552 | 0.1569 | 0.1247 |
| BRC11 | 0.1443 | 0.1549 | 0.0721 | 0.1488 | 0.1512 | 0.1695 | 0.1538 | 0.1465 | 0.1702 | 0.1779 |
| BRC12 | 0.1494 | 0.1583 | 0.0678 | 0.1326 | 0.1058 | 0.1519 | 0.1489 | 0.1614 | 0.1540 | 0.1599 |
| BRC13 | 0.1597 | 0.1573 | 0.1010 | 0.1518 | 0.1540 | 0.1624 | 0.1683 | 0.1617 | 0.1636 | 0.1712 |
| BRC14 | 0.1281 | 0.1376 | 0.0628 | 0.1269 | 0.1337 | 0.1294 | 0.1392 | 0.1290 | 0.1527 | 0.1358 |
| BRC15 | 0.1254 | 0.1358 | 0.0746 | 0.1219 | 0.1213 | 0.1512 | 0.1108 | 0.1404 | 0.1406 | 0.1482 |

**Table 8** (continued)

| Code | BRC1 | BRC2 | BRC3 | BRC4 | BRC5 | BRC6 | BRC7 | BRC8 | BRC9 | BRC10 |
|---|---|---|---|---|---|---|---|---|---|---|
| BRC16 | 0.0929 | 0.1163 | 0.0566 | 0.0902 | 0.1247 | 0.1319 | 0.1012 | 0.1069 | 0.1194 | 0.1379 |
| BRC17 | 0.1616 | 0.1577 | 0.1251 | 0.1294 | 0.1622 | 0.1621 | 0.1689 | 0.1633 | 0.1642 | 0.1711 |
| BRC18 | 0.1260 | 0.1376 | 0.0600 | 0.0857 | 0.1320 | 0.1150 | 0.1227 | 0.1272 | 0.1285 | 0.1464 |
| BRC19 | 0.1239 | 0.1346 | 0.0734 | 0.0837 | 0.1167 | 0.1247 | 0.1212 | 0.1255 | 0.1266 | 0.1436 |
| BRC20 | 0.1527 | 0.1489 | 0.0970 | 0.1225 | 0.1450 | 0.1631 | 0.1508 | 0.1542 | 0.1555 | 0.1616 |

| Code | BRC11 | BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.1541 | 0.1506 | 0.1836 | 0.1375 | 0.1578 | 0.1166 | 0.1427 | 0.1428 | 0.1705 | 0.1852 |
| | 0.1196 | 0.1245 | 0.1572 | 0.1360 | 0.1097 | 0.0789 | 0.1059 | 0.1133 | 0.1306 | 0.1583 |
| | 0.0700 | 0.0723 | 0.1112 | 0.1111 | 0.0814 | 0.0568 | 0.0948 | 0.0718 | 0.1016 | 0.0989 |
| | 0.0855 | 0.1185 | 0.1229 | 0.1035 | 0.1293 | 0.0794 | 0.1128 | 0.0966 | 0.0870 | 0.1113 |
| | 0.0771 | 0.0811 | 0.1365 | 0.0797 | 0.1067 | 0.0664 | 0.0890 | 0.1213 | 0.1006 | 0.1460 |
| | 0.1032 | 0.0831 | 0.1486 | 0.0831 | 0.1302 | 0.0686 | 0.1052 | 0.0999 | 0.1042 | 0.1487 |
| | 0.1333 | 0.1387 | 0.1570 | 0.1491 | 0.1210 | 0.0921 | 0.1196 | 0.1263 | 0.1334 | 0.1678 |
| | 0.1502 | 0.1467 | 0.1775 | 0.1451 | 0.1314 | 0.1257 | 0.1386 | 0.1367 | 0.1419 | 0.1690 |
| | 0.1183 | 0.1200 | 0.1397 | 0.1328 | 0.0920 | 0.0738 | 0.1272 | 0.1334 | 0.1397 | 0.1633 |
| | 0.0987 | 0.1508 | 0.1715 | 0.1391 | 0.1379 | 0.1318 | 0.1082 | 0.1533 | 0.1595 | 0.1631 |
| | 0.0985 | 0.1327 | 0.1662 | 0.1431 | 0.1434 | 0.1237 | 0.1121 | 0.1579 | 0.1624 | 0.1675 |
| | 0.0973 | 0.1004 | 0.1591 | 0.1258 | 0.1239 | 0.1295 | 0.1073 | 0.1402 | 0.1560 | 0.1693 |

**Table 8** (continued)

| BRC11 | BRC12 | BRC13 | BRC14 | BRC15 | BRC16 | BRC17 | BRC18 | BRC19 | BRC20 |
|---|---|---|---|---|---|---|---|---|---|
| 0.1293 | 0.1362 | 0.1330 | 0.1471 | 0.1335 | 0.1357 | 0.1406 | 0.1499 | 0.1550 | 0.1707 |
| 0.1347 | 0.1294 | 0.1474 | 0.0891 | 0.0885 | 0.0726 | 0.1114 | 0.0945 | 0.0984 | 0.1491 |
| 0.0851 | 0.1029 | 0.1342 | 0.0895 | 0.0876 | 0.1110 | 0.0973 | 0.1308 | 0.1452 | 0.1345 |
| 0.0763 | 0.1203 | 0.1368 | 0.1062 | 0.1062 | 0.0635 | 0.0887 | 0.1237 | 0.1140 | 0.1256 |
| 0.1417 | 0.1466 | 0.1700 | 0.1352 | 0.1327 | 0.0999 | 0.1010 | 0.1499 | 0.1564 | 0.1811 |
| 0.1224 | 0.1149 | 0.1330 | 0.1139 | 0.1253 | 0.0985 | 0.0828 | 0.0906 | 0.1354 | 0.1461 |
| 0.1207 | 0.1123 | 0.1303 | 0.0993 | 0.1238 | 0.0712 | 0.1063 | 0.1159 | 0.0933 | 0.1315 |
| 0.1356 | 0.1271 | 0.1707 | 0.1275 | 0.1016 | 0.0814 | 0.1340 | 0.1296 | 0.1472 | 0.1246 |

**Table 9** The dispatch node set calculation

| | |
|---|---|
| The ordered triplets set | {(0.1852, 1, 20), (0.1848, 1, 10), (0.1836, 1, 13), (0.1811, 17, 20), (0.1779, 11, 10), (0.1778, 1, 9)…, (0.0664, 5, 16), (0.0635, 16, 16), (0.0628, 14, 3), (0.06, 18, 3), (0.0569, 4, 3), (0.0568, 3, 16), (0.0566, 16, 3), (0.0488, 3, 3)} |
| The Dispatch Node set $T^{Di}$ | {1, 1, 1, 17, 11, 1, 8, 1, 1, 10, 13, 17, 13, 20, 1, 11, 17, 11, 12, 8, 17, 8, 13, 7, 11, 2…, 11, 3, 19, 3, 5, 6, 12, 2, 3, 5, 16, 14, 18, 4, 3, 16, 3} |
| $MDE_t^{Di}$ values | {0, 0, 0, 0.0654, 0.0494, 0.077, 0.0581, 0.0782, 0.0959, 0.0764, 0.0619, 0.053, 0.0445, …, 0.0001, 0.0001, 0.0001, 0.0001, 0.0001, 0.0001, 0.0001, 0.0001, 0} |
| Maximum $MDE_t^{Di}$ | 0.095894 |
| Corresponding $T_t^{Di}$ | {1, 1, 1, 17, 11, 1, 8, 1, 1} = {1, 17, 11, 8} |

### 3.3.1 Transforming the defuzzified total relation matrix in *Table 8* into an ordered triplet set O

### 3.3.2 Determining the second component from the set O generates a new set called ordered Dispatch node set D

### 3.3.3 Approximating the mean de-entropy (MDE) value for elements of the dispatch node set

Considering the first $t$ elements of $T^{Di}$ as a new set $T_t^{Di}$ t, we allocated the probability of different elements and then calculated the de-entropy $H^D$ of the set by adopting Eqs. (16) and (17). At first, the value of $t$ was put as 1, and the value of $t$ was increased by 1 up to the total number of elements.

$$H^D = H\left(\frac{1}{n}, \frac{1}{n}, \ldots, \frac{1}{n}\right) - H(p_1, p_2, \ldots, p_n) \tag{16}$$

Here, $n$ is the number of elements, and $p_n$ is the probability of *nth* element

$$MDE_t^{Di} = \frac{H_t^{Di}}{N\left(T_t^{Di}\right)} \tag{17}$$

### 3.3.4 Determining the maximum value of mean de-entropy of a dispatch node set

The selection of the highest value from the set of $MDE_t^{Di}$ values and the corresponding $T_t^{Di}$ is provided in Table 9.

### 3.3.5 Calculating the received node sets

Steps 3.3.2 to 3.3.4 are repeated to obtain an ordered receive node-set $T^{Re}$. The receiving node set calculation is provided in Table 10.

**Table 10** Receiving node set calculation

| | |
|---|---|
| The ordered triplets set | {(0.1852, 1, 20), (0.1848, 1, 10), (0.1836, 1, 13), (0.1811, 17, 20), (0.1779, 11, 10), (0.1778, 1, 9)…, (0.0664, 5, 16), (0.0635, 16, 16), (0.0628, 14, 3), (0.06, 18, 3), (0.0569, 4, 3), (0.0568, 3, 16), (0.0566, 16, 3), (0.0488, 3, 3)} |
| The Receive Node set $T^{Re}$ | {20, 10, 13, 20, 10, 9, 13, 8, 7, 13, 10, 10, 20, 13, 19, 9, 13, 6,…,16, 11, 3, 16, 3, 3, 4, 16, 16, 3, 3, 3, 16, 3, 3} |
| $MDE_t^{Re}$ values | {0, 0, 0, 0.0196, 0.0146, 0.0142, 0.0086, 0.01, 0.0094, 0.016, 0.0199, 0.0265,…, 0.0005, 0.0005, 0.0004, 0.0004, 0.0004, 0.0003, 0.0003, 0.0003, 0} |
| Maximum $MDE_t^{Re}$ | 0.031118 |
| Corresponding $T_t^{Re}$ | {20, 10, 13, 20, 10, 9, 13, 8, 7, 13, 10, 10, 20, 13, 19, 9, 13, 6, 20, 20, 7, 10, 7, 20, 20, 10, 1, 7, 13} = {20, 10, 13, 9, 8, 7, 19, 6, 1} |

### 3.3.6 Determining the threshold value

We determined $T_{max}^{Di}$ by selecting the first elements from $T^{Di}$. Similarly, we determined $T_{max}^{Re}$. Then, $T^{Th}$ was calculated as the intersection set of $T_{max}^{Di}$ and $T_{max}^{Re}$. The value from the last element of $T^{Th}$ was the final threshold value.

### 3.3.7 Obtain the impact-relations map

In this step, the threshold value links in the total relation matrix were included in the impact relation map.

## 4 Results and discussion

In the present study, a fuzzy DEMATEL approach was employed to examine the most substantial BRCs for the implementation of PRS. Further, the identified BRCs were ranked concerning their prominence based on the (D + R) values as follows: BRC13 > BRC1 > BRC10 > BRC20 > BRC8 > BRC7 > BRC9 > BRC2 > BRC17 > BRC11 > BRC12 > BRC6 > BRC19 > BRC18 > BRC14 > BRC15 > BRC5 > BRC4 > BRC16 > BRC3 (Table 11).

This study presents the cause-and-effect diagram between the identified potential BRCs for PRS in Fig. 2.

### 4.1 Cause-and-effect group BRCs

The BRCs for PRS comprising of positive values were mentioned as the cause group BRCs. These were the most influencing BRCs that obstruct the implementation of PRS. Based on the (D-R) value, the cause group BRCs were organized as highlighted in Table 11. The cause BRCs were ranked as BRC17 > BRC11 > BRC1 > BRC12 > BRC16 > BRC3 > BRC8 > BRC15. Further, the BRCs with negative values were mentioned as effect group BRCs. The effect group BRCs were organized based on the (D-R) value, as highlighted in Table 11. The effect BRCs were ranked as BRC14 > BRC13 > BRC7 > BRC2 > BRC18 > BRC4 > BRC10 > BRC20 > BRC9 > BRC19 > BRC5 > BRC6.

**Table 11** The score for each BRC for PRS

| Code | Blockchain readiness challenges (BRCs) | D | R | D + R | D-R | Rank | Cause/Effect |
|------|----------------------------------------|---|---|-------|-----|------|--------------|
| BRC1 | Inadequate mechanism for BCT pursuit in PRS | 3.086075 | 2.73583 | 5.821905 | 0.350245 | 2 | *Cause* |
| BRC2 | Challenges in assimilating PRS and BCT | 2.625129 | 2.665802 | 5.290931 | − 0.04067 | 8 | *Effect* |
| BRC3 | Lack of customer cognizance towards PRS and BCT | 1.805217 | 1.56209 | 3.367306 | 0.243127 | 20 | *Cause* |
| BRC4 | Infantile challenge of BCT | 2.099013 | 2.270101 | 4.369114 | − 0.17109 | 18 | *Effect* |
| BRC5 | High cost linked with BCT implementation | 2.105082 | 2.563251 | 4.668333 | − 0.45817 | 17 | *Effect* |
| BRC6 | Reluctant to convert to a new arrangement | 2.191419 | 2.806634 | 4.998053 | − 0.61521 | 12 | *Effect* |
| BRC7 | Lack of organizational policies and frameworks for BCT adoption | 2.666926 | 2.698196 | 5.365121 | − 0.03127 | 6 | *Effect* |
| BRC8 | Inadequate financing for PRS exercises | 2.908635 | 2.794014 | 5.702649 | 0.114621 | 5 | *Cause* |
| BRC9 | Inadequate organizational structures to support PRS | 2.501923 | 2.836575 | 5.338497 | − 0.33465 | 7 | *Effect* |
| BRC10 | Lack of IT arrangements to assist PRS | 2.770232 | 3.02582 | 5.796051 | − 0.25559 | 3 | *Effect* |

**Table 11** (continued)

| Code | Blockchain readiness challenges (BRCs) | D | R | D + R | D-R | Rank | Cause/Effect |
|------|------------------|---|---|-------|-----|------|--------------|
| BRC11 | Security challenges to BCT implementation | 2.896464 | 2.251629 | 5.148092 | 0.644835 | 10 | *Cause* |
| BRC12 | Lack of technological maturity towards PRS | 2.699062 | 2.408936 | 5.107998 | 0.290127 | 11 | *Cause* |
| BRC13 | Inadequate standards for PRS operations | 2.981986 | 2.986471 | 5.968457 | − 0.00449 | 1 | *Effect* |
| BRC14 | Market impediments and uncertainty | 2.390389 | 2.393708 | 4.784097 | − 0.00332 | 15 | *Effect* |
| BRC15 | Traceability and visibility concern with BCT adoption | 2.388329 | 2.363956 | 4.752285 | 0.024373 | 16 | *Cause* |
| BRC16 | Limited scalability with BCT implementation in PRS | 2.139273 | 1.876996 | 4.016268 | 0.262277 | 19 | *Cause* |
| BRC17 | Lack of awareness and expertise towards BCT adoption | 2.98002 | 2.225281 | 5.205301 | 0.75474 | 9 | *Cause* |
| BRC18 | Data processing and storage challenges with BCT in PRS | 2.343949 | 2.478475 | 4.822424 | − 0.13453 | 14 | *Effect* |
| BRC19 | Privacy challenges with BCT | 2.27854 | 2.632442 | 4.910982 | − 0.3539 | 13 | *Effect* |
| BRC20 | Lack of governance and standards | 2.730457 | 3.011916 | 5.742373 | − 0.28146 | 4 | *Effect* |

**Cause Effect Diagram**
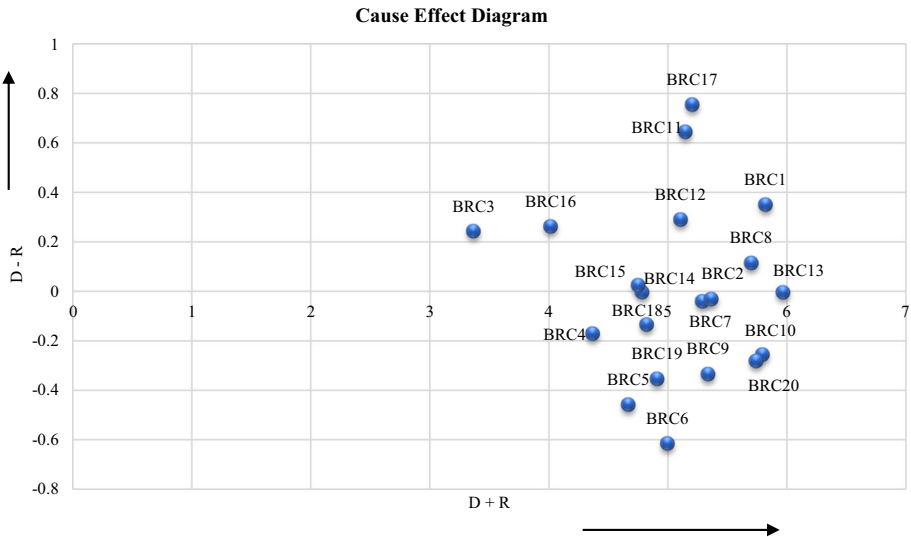


**Fig. 2** Causal diagram for the BRCs for PRS

In the cause group, there were eight BRCs. *Lack of awareness and expertise towards BCT adoption (BRC17)* and *Security challenges to BCT implementation (BRC11)* were identified as the most critical BRCs that obstruct the PRS implementation. These BRCs can generate an effect on the other BRCs. The potential barrier for organizations connected with blockchain practices is a lack of awareness and understanding concerning the working of BCT (Kouhizadeh et al., 2021). Still, organizations are unaware of the potential benefits of BCT adoption in their organizations. There is a requirement for professionals to spread the knowledge among the employees regarding BCT implementation in organizations (Lopes et al., 2021). *Security challenges to BCT implementation (BRC11)* was among the major causal BRCs for PRS implementation. In BCT, transaction recordings are accumulated and spread in a digital ledger form comprising linked blocks of the transaction (Ye et al., 2020). There is no central management control mechanism in BCT. Several security challenges occur with BCT adoption due to the transactional setting in BCT and increased popularity.

*Inadequate mechanism for BCT pursuit in PRS (BRC1)* was the third-ranked causal BRC. The lack of expertise towards BCT among the organizations is a significant barrier to its implementation. The organizations successfully practicing BCT can provide precious perspectives and recommendations that can be implemented for BCT adoption in PRS. Further, synchronization and understanding among the organizations would result in enhanced BCT pursuit in PRS. This brings in the requirement for an adequate mechanism for BCT pursuit in PRS.

*Lack of technological maturity towards PRS (BRC12)* is another potential BRC under the cause group. BCT is accepted mainly in industries for its distinctive management of transaction settings. A lack of technological maturity for BCT is seen as one of the reasons for its unacceptance by organizations in PRS implementation (Richter et al., 2018). There is a requirement to commence several workshops and programs by the organizations to discover the BCT widely.

*Limited scalability with BCT implementation in PRS (BRC16)* is ranked fifth in the cause group. Scalability is necessary for organizations due to the large spread environment of

their establishments. Organizations perform millions of transaction settings crosswise their businesses (Mazlan et al., 2020). In some cases, the limitations of scalability and a limited transaction setting in BCT contribute to substantial delays for the organizations and consumers (Biswas et al., 2018). Therefore, the scalability concern is a vital barrier to cater for efficient PRS implementation.

*Lack of customer cognizance towards PRS and BCT (BRC3)* is ranked sixth BRC in the cause group. The studies specific to PRS and BCT are still in a nascent stage. BCT's implementation contributes to the coordination of sustainable practices with environmental regulations (Saberi et al., 2019). Most customers relate BCT and cryptocurrency as similar. Therefore, negative thoughts against cryptocurrency occasionally transfer towards BCT (Jain et al., 2020). Lack of customer cognizance towards BCT is a barrier to its implementation in organizations.

*Inadequate financing for PRS exercises (BRC8)* is the seventh-ranked BRC in the causal group. Organizations are eager to invest in technologies where they expect a high return on investments. An underestimation between traditional methods and the recent era of digitalization might cause difficulty in sharing resources and decision-making regarding investments (Koc & Bozdag, 2017). Therefore, the organizations are reluctant to invest in BCT exercises for PRS.

*Traceability and visibility concern with BCT adoption (BRC15)* is ranked eighth in the cause group. BCT can facilitate increased visibility and traceability through extended correlations with DSCs (Kharlamov & Parry, 2018). The supply chain experts consider visibility and traceability essential drivers of cross-organization collaboration (Rogerson & Parry, 2020). With technological advancements, BCT is perceived to permit ample visibility of movements along the recovery chain (Majeed & Rupasinghe, 2017). Therefore, it becomes essential for the organizations to focus on the traceability and visibility concern with BCT adoption in PRS.

There are 12 BRCs in the effect group—the eight causal BRCs influence these 12 BRCs to implement PRS in the manufacturing industry. *Market impediments and uncertainty (BRC14)* was near the causal BRC group and less influenced by causal BRCs. Further, *Inadequate standards for PRS operations (BRC13)*, *Lack of organizational policies and frameworks for BCT adoption (BRC7)*, *Challenges in assimilating PRS and BCT (BRC2)*, *Data processing and storage challenges with BCT in PRS (BRC18)*, *Infantile challenge of BCT (BRC4)*, *A lack of IT arrangements to assist PRS (BRC10)*, *Lack of Governance and standards (BRC20)*, *Inadequate organizational structures to support PRS (BRC9)*, *Privacy challenges with BCT (BRC19)*, *High costs linked with BCT implementation (BRC5)* and *Reluctant to convert to a new arrangement (BRC6)* are the BRCs in effect BRC group. These BRCs are easily influenced by the causal BRCs. To effectively implement PRS in the manufacturing industry, it is beneficial to identify the cause-and-effect BRCs. This study can assist managers in identifying these cause-and-effect relations and advance practical understandings to implement PRS in the manufacturing industry.

Further, the MMDE algorithm was applied after the DEMATEL approach to generate the threshold value. Based on MMDE analysis, the generated threshold value of 0.167248 was used to obtain the interactions among the BRCs for PRS with the most potential in Table 12.

From the MMDE analysis, *an inadequate mechanism for BCT pursuit in PRS (BRC1), challenges in assimilating PRS and BCT (BRC2), reluctance to convert to a new arrangement (BRC6), a lack of organizational policies and frameworks for BCT adoption (BRC7), inadequate financing for PRS exercises (BRC8), inefficient organizational structures to support PRS (BRC9), a lack of IT arrangements to assist PRS (BRC10), security challenges for BCT implementation (BRC11), lack of technological maturity towards PRS (BRC12), inadequate*

**Table 12** Threshold value

| | |
|---|---|
| $T_{max}^{Di}$ | {(0.185249160623833, 1, 20), (0.18481379363312, 1, 10), (0.183627937916748, 1, 13), (0.181106269457534, 17, 20), (0.17792210813375, 11, 10), (0.177828008519286, 1, 9), (0.177471993130536, 8, 13)} |
| $T_{max}^{Re}$ | {(0.185249160623833, 1, 20), (0.18481379363312, 1, 10), (0.183627937916748, 1, 13), (0.181106269457534, 17, 20), (0.17792210813375, 11, 10), (0.177828008519286, 1, 9), (0.177471993130536, 8, 13), (0.176056355034923, 1, 8), (0.171945719696714, 1, 7), (0.171549518138438, 10, 13), (0.17122506239988, 13, 10), (0.171050417302425, 17, 10), (0.170746536190432, 13, 20), (0.170667101090551, 20, 13), (0.170535722700878, 1, 19), (0.170177808166487, 11, 9), (0.169982506525479, 17, 13), (0.169469421016332, 11, 6), (0.169315344097307, 12, 20), (0.169019917119026, 8, 20), (0.168934270330163, 17, 7), (0.168592226113708, 8, 10), (0.168319549252442, 13, 7), (0.167826280904, 7, 20), (0.167504953109114, 11, 20), (0.167322600861131, 2, 10), (0.167247572766832, 8, 1)} |
| $T^{Th}$ | {(0.185249160623833, 1, 20), (0.18481379363312, 1, 10), (0.183627937916748, 1, 13), (0.181106269457534, 17, 20), (0.17792210813375, 11, 10), (0.177828008519286, 1, 9), (0.177471993130536, 8, 13), (0.176056355034923, 1, 8), (0.171945719696714, 1, 7), (0.171549518138438, 10, 13), (0.17122506239988, 13, 10), (0.171050417302425, 17, 10), (0.170746536190432, 13, 20), (0.170667101090551, 20, 13), (0.170535722700878, 1, 19), (0.170177808166487, 11, 9), (0.169982506525479, 17, 13), (0.169469421016332, 11, 6), (0.169315344097307, 12, 20), (0.169019917119026, 8, 20), (0.168934270330163, 17, 7), (0.168592226113708, 8, 10), (0.168319549252442, 13, 7), (0.167826280904, 7, 20), (0.167504953109114, 11, 20), (0.167322600861131, 2, 10), (0.167247572766832, 8, 1)} |
| Threshold value | 0.167248 |

standards for PRS operations (BRC13), lack of awareness and expertise towards BCT adoption (BRC17), privacy challenges with BCT (BRC19) and lack of governance and standards (BRC20) are identified as most influential BRCs. The impact relationship map reflects the relations among BRCs for PRS which is presented in Fig. 3.

### 4.2 Correlations among the BRCs

The different (D + R) values reflected in Table 10 represent the impact of BRCs. The higher the value, the stronger the participation of that BRC is to obstruct the implementation of PRS. The BRCs can be arranged as BRC13, BRC1, BRC10, BRC20, BRC8, BRC7, BRC9, BRC2, BRC17, BRC11, BRC12, BRC6, BRC19, BRC18, BRC14, BRC15, BRC5, BRC4, BRC16, and BRC3. In the present study, it was perceived that each BRC is directly persuaded by other BRCs. *Inadequate standards for PRS operations (BRC13)* determined the highest correlation with other BRCs. Effective PRS implementation requires monitoring, sustaining, and enhancing internal and collaborative processes (Dwivedi et al., 2020). If the effective implementation of the processes is not performed, there will be a significant loss concerning labor and services. In PRS, the transformations in a PRS require financial investments and human resources. Therefore, there is a requirement for a set of standards for PRS operations. By way of contrast, *lack of customer cognizance towards PRS and BCT (BRC3)* is the least correlated with other BRCs. In the era of digitalization, consumers search for the implementation of advanced technologies in supply chains (Wang et al., 2019). There is a lack of awareness and knowledge among the consumers in the context of BCT and PRS.
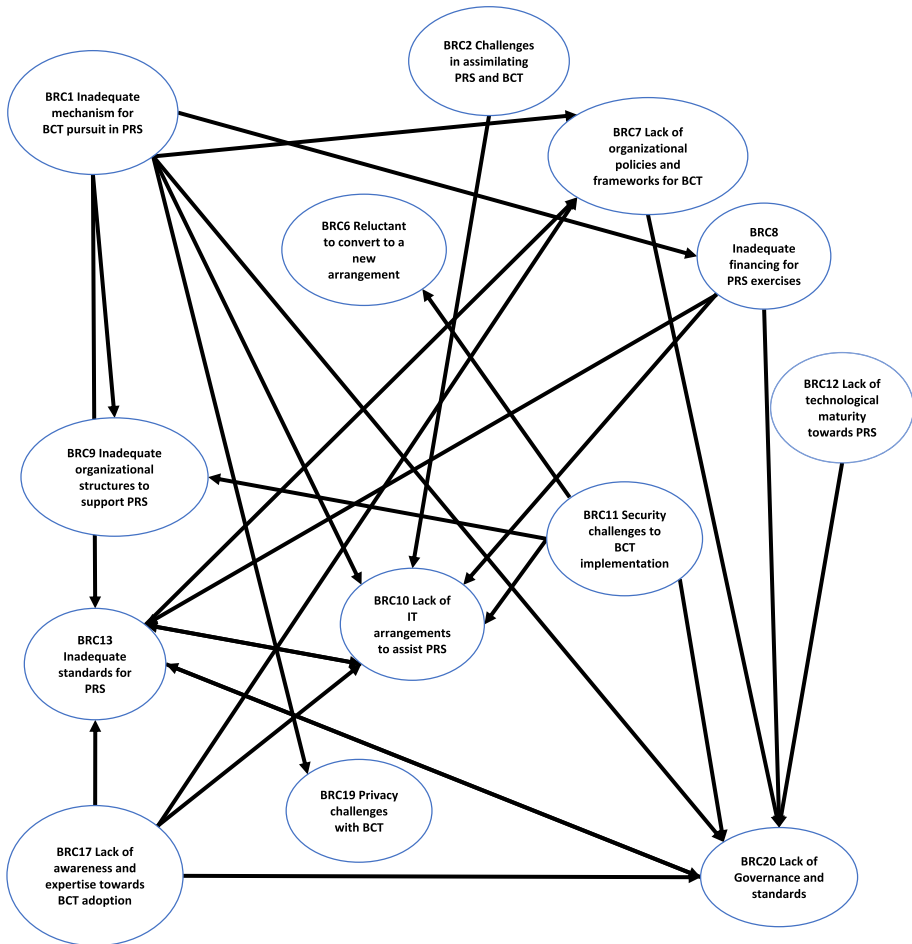
**Fig. 3** Impact-relations map for BRC to PRS

This brings the requirement for effective educational programs, conferences, and workshops to make the customer aware of the benefits of BCT adoption. Therefore, effective assessment measures based on BCT adoption will assist the manufacturing industries to remain updated with the latest technologies.

## 5 Managerial and practical implications

This study presents some managerial and practical implications. From the results, causal BRCs for BCT adoption in PRS have been explored. The development of BRCs can be affected by the causal group. Measures should be suggested to improve the causal BRCs for BCT adoption in PRS. This study is beneficial for manufacturing organizations concerned with implementing BCT in PRS by eliminating potential BRCs through organized methods

in the post-COVID-19 era (Chowdhury et al., 2021). Further, several valuable implications are recommended to managers in the manufacturing industry based on the research findings:

***Implication 1***:   In this study, *lack of awareness and expertise towards BCT adoption* is reflected as one of the important barriers in the list of BRCs. A higher level of awareness and expertise is essential for adopting BCT in PRS, resulting in efficient execution of PRS in the post-COVID-19 era. Industry managers should ensure that the economic advantages are achieved in their organization with the execution of BCT practices. Further, managers are suggested to learn from the expertise of other organizations executing such practices.

***Implication 2***:   This study's findings reflect that *security challenges to BCT implementation* is an essential barrier for the implementation of BCT in PRS. The blockchain works on the concept of decentralization that structures data into blocks with multiple transaction settings. Although BCT can provide an error-free set of transactions, there are possibilities of security issues. Manufacturing organizations are reluctant to adopt BCT practices because of security concerns.

***Implication 3***:   *Challenges in assimilating BCT and PRS* is an important BRC for BCT adoption in PRS. Manufacturing industries are not conscious of the regulations and policies specific to BCT adoption in PRS, resulting in inconvenience in implementing the policies and integrating BCT and PRS.

***Implication 4***:   The *high costs linked with BCT implementation* is another significant barrier. Most manufacturing organizations are reluctant to invest money and resources to adopt BCT in PRS. Industry managers are encouraged to feature the advantages and economic benefits of BCT adoption in PRS.

The findings of this study can help industry managers in successfully implementing BCT practices for BCT adoption by eliminating BRCs. This study has analyzed BRCs for PRS implementation and examined the ranking and nature of these BRCs. The ranking of the cause-and-effect BRCs can assist decision-makers in advancing strategic policies during PRS implementation in the post-COVID-era. Managers can consider this study as a benchmark for enhancing the manufacturing industry by adopting BCT in PRS.

## 6 Conclusions and future research directions

BCT, which primarily encouraged the Bitcoin cryptocurrency, is a tamper-resistant distributed ledger that might eradicate business frictions hindering innovation adoption (Gausdal et al., 2018). Most industries are confined to traditional methods. BCT is a recent research domain and is unknown to most industries. These industries are not organized to attain the advantages obtainable via BCT adoption. Therefore, it becomes crucial to identify the BRCs through the implementation of PRS in the manufacturing industry.

In this study, twenty BRCs for PRS implementation were identified through a literature review and expert recommendations. Further, the fuzzy DEMATEL methodology, which considers uncertainty, was adopted to assess the identified BRCs. In the present study, the fuzzy DEMATEL methodology was used to transform qualitative information into quantitative evaluations and identify the most significant BRCs under the cause-and-effect groups that obstruct PRS's execution. The significance of each influencing BRC on PRS's implementation has been effectively identified. Further, the causal interaction among each BRC has been produced through an organized framework. The findings from the study reflect that there are eight BRCs in the cause group and 12 BRCs in the effect group. In the present study, *lack of awareness and expertise towards BCT adoption (BRC17)* and *security challenges to BCT implementation (BRC11)* appeared as the most influential BRCs in this group. This reflects that other BRCs can easily influence these BRCs. The results from this study can assist the organizations in making strategic decisions when shifting from a traditional system to PRS.

In emerging economies, manufacturing industries are reluctant to adopt digital technologies. There can be various reasons concerning the lack of information for such reluctance, including high investments and improper infrastructure. Therefore, requirements for adopting BCT in PRS have become essential. To the best of our understanding, there is no pre-existing study that has evaluated the BRCs for PRS in the context of the manufacturing industry. The present study contributes in three main ways. First, the study helps organizations generate cognizance of the essential BRCs for PRS implementation. Second, the study identifies the interactions between the BRCs for PRS adoption and assembles the BRCs into cause-and-effect groups. Third, the study identifies an impact relationship map for the potential BRCs for PRS by adopting an MMDE approach. The main contribution of this study to the present literature is to suggest a framework that industry managers could employ to address the BRCs and advance suitable measures to cater to them for the successful implementation of BCT practices in PRS.

There are a few limitations to this study. The present study adopts BCT that has the potential for enhancing the PRSs in the post-COVID-19 era. The study identifies a list of important BRCs to PRS and recommends measures to cater to them for the successful implementation of BCT in manufacturing industries. In the present study, the number of partaking experts is acceptable in comparison to the current literature. However, more experts can be included in the survey to confirm the exactness of the results. Further, experts considered in this study are from a particular country. In the future, studies could be performed by selecting experts from multiple developed and developing countries to generalize the results. In future studies, other MCDM techniques such as fuzzy ANP, fuzzy BWM, and TISM can also be implemented to evaluate the potential BRCs in PRS and to compare the findings.

# Appendix 1

| Questionnaire on Modeling the Blockchain Readiness Challenges for Product Recovery System |
|---|
| **The intention of this questionnaire is to accumulate data for modeling the blockchain readiness challenges for product recovery system. Please spare a few minutes in responding to the questions. Your time and assistance is highly appreciated.** |
| **Part 1** |
| **Section A: Details of the Respondent's** |

| Name (Optional): | Gender: ☐ Male | ☐ Female | Age: |
|---|---|---|---|
| Work Experience (Years): | Area Expertise: | | |
| Education: | Company / Institute Name: | | |
| Role in the Company / Institute: | | | |
| Mobile No. (Optional): | Email (Optional): | Address (Optional): | |

| Part 2 |
|---|
| **Section B: Judgement by the experts: As per the scale, please fill the measure to which the elimination of the challenge is important for adoption of blockchain technology in product recovery system** |
| **Scale**  Very High (VH)   High (H)   Low (L)   Very Low (VL)   No |

| Challenges | Answer (VH/H/L/VL/No) |
|---|---|
| 1. Inadequate mechanism for BCT pursuit in PRS | |
| 2. Challenges in assimilating PRS and BCT | |
| 3. Lack of customer cognizance towards PRS and BCT | |
| 4. Infantile challenge of BCT | |
| 5. High cost linked with BCT implementation | |
| 6. Reluctant to convert to a new arrangement | |
| 7. Lack of organizational policies and frameworks for BCT adoption | |
| 8. Inadequate financing for PRS exercises | |
| 9. Inadequate organizational structures to support PRS | |
| 10. Lack of IT arrangements to assist PRS | |
| 11. Security challenges to BCT implementation | |
| 12. Lack of technological maturity towards PRS | |
| 13. Inadequate standards for PRS operations | |
| 14. Market impediments and uncertainty | |
| 15. Traceability and visibility concern with BCT adoption | |
| 16. Limited scalability with BCT implementation in PRS | |
| 17. Lack of awareness and expertise towards BCT adoption | |
| 18. Data processing and storage challenges with BCT in PRS | |
| 19. Privacy challenges with BCT | |
| 20. Lack of Governance and standards | |

| **Section C: Remarks/ Suggestions (If Any):** |
|---|
| **Thanks for sharing your valuable time** |

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