

RESEARCH PAPER

Implementation Barriers for Digital Transformation of Perishable Food Supply Chain in Pakistan

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ABSTRACT

Goal: The current study intends to identify the key barriers affecting Digital Transformation (DT) in the Pakistan Perishable Food Supply Chain (PFSC). Additionally, it also focuses on developing contextual relationships between the identified barriers.

Design/Methodology/Approach: A hybrid approach, comprising qualitative and quantitative methodologies were adopted. Identification of the barriers was done using a qualitative approach through a detailed and systematic literature review, along with employing the expert judgment method. Whereas, the quantitative section analyzed these identified barriers using Total Interpretive Structural Modeling (TISM). Further, based on their driving and dependence powers, Fuzzy-MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) was used to categorize these barriers into four groups, named as independent, linkage, autonomous, and dependent.

Results: This study highlighted that lack of support, reward, and recognition, along with poor IT infrastructure, high investment and maintenance costs, exert an impact on the system, recommending the primary role of these elements towards the DT process. Comparatively, other barriers play a relatively trivial role in this case.

Limitations of the investigation: Due to the subjectivity of the respondents, particularly those from Pakistan's PFSC, the findings of this research may not be generalized. However, it may prove beneficial to the economies facing similar circumstances and environments around the world.

Implications: Outcomes from this research work may prove helpful to the Food Supply Chain (FSC) experts to ensure a systematically controlled and progressively elaborated smooth transition towards digitalization of the Supply Chain (SC). Apart, this research also contributes to the existing body of knowledge by proposing an effective hybrid methodology employing TISM and Fuzzy MICMAC for conducting exploratory studies. It may prove beneficial to the economies facing similar circumstances and environments around the world. Further, the study results can be replicated across different sectors and regions.

Originality/value: This study provides a deep insight by establishing the hierarchy of barriers confronted in PFSC. Employing an integrated innovative approach, TISM and Fuzzy-MICMAC enable field experts to devise better strategies in this area.

Keywords: Digital Transformation; Perishable Food Supply Chain; Barriers; TISM; PRISMA.

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1 INTRODUCTION

With a growing population, challenges to meet human needs, particularly for food production, preservation, and waste control, are getting higher for the emerging countries (Lwesya and Achanta, 2022). Events such as the COVID-19 pandemic and the ongoing global conflicts has further raised the concerns for FSC (Zhao et al., 2023).

Further, preservative/ hygiene-related practices and short product shelf life are proving difficult to comply with established standards affecting health, and undermining customer trust. The recent food scandals, which eroded consumer confidence and brands' credibility, are Sudan red, Clenbuterol, Sanlu toxic milk powder, Trench oil, Escherichia coli, and Salmonella (Haji et al., 2020).

The FSC processes vary in accordance with the purpose to transform raw agricultural products to meet serving and consumption requirements (Ghode et al., 2020). The term Perishable foods among FSC marks a most sensitive class of products, susceptible to quality degradation during manufacturing, storage, and transportation (Haji et al., 2020). A limited shelf life or perishable products include vegetables, fruits, dairy products, seafood, and meat. Perishable goods could produce harmful impacts upon use after a certain time, with varying degrees of severity depending upon additional factors (Kumar et al., 2021a). Therefore, this vulnerability largely reduces the reliability of perishable food products, besides the challenges of their preservation and use within the best time.

The Pakistan food sector contributes 23% to the country's GDP and accounts for 43% of employment (Usman, 2016, Panigrahi et al., 2024). However, this sector received minimal attention despite huge market volume (Dong et al., 2023). Under these conditions, digitalization of the FSC could be expected to offer a solution to such challenges methodically (Sharma et al., 2021). Since the adoption of digital technologies for transforming operations involve replacement of manual processes with digital ones (Dash et al., 2022). So, a holistic review of the processes and operations to identify areas of critical importance with thorough change analysis impact serves as the key consideration (Alieva and Powell, 2023). The next step is then merely a question of choice of technologies to match the needs, such as whether to employ IoT, Big Data, and other tools for enhanced information sharing (Nayal et al., 2021a, Rejeb et al., 2021). To illustrate, Walmart China drastically reduced pork tracking lead time by adopting blockchain technology (Rao and Clarke, 2020). In the same way, (Chen, 2017) proposed a cyber-physical system for poor-quality food detection and elimination from its production system. The adoption of emerging technologies can also strengthen decision-making in the PFSC (Xu et al., 2020). To manage next-generation digital value chains, businesses should consider advanced technologies to manage and control SC operations effectively (Akram et al., 2023).

Likewise, (Gouvea et al., 2022) explored the role of digital technologies to address increasing food demand challenges. (Aamer et al., 2021) found it effective in food safety and quality-related applications. (Ardra and Barua, 2023) 2023 reported the potential for waste control and loss of food. (Joshi et al., 2023) added to the advantageous use of digital technologies towards food safety and control of health hazards. (de Souza et al., 2021) pointed out its significance in addressing limited shelf life-related matters with food items. (Al Mashalah et al., 2022) brought focus to another important dimension related to stakeholder satisfaction and trust. Further, (Chauhan and Singh, 2019) emphasized the role of DT in variation control, adding to cost savings and product reliability enhancements. (Agarwal and Ojha, 2022) owing to the benefits that digital technologies offer, they admitted that organizations opting for these technologies could gain market competitiveness, business expansions, and innovation capabilities to lead the future.

However, the implementation and utilization remain challenging, as it was found that around 80% failure for the organizations that initiated transformation towards digitalization experienced failure (Oludapo et al., 2024). In one such study (Ribeiro-Navarrete et al., 2023) added that the transformation failures are barrier-driven, hindering the adoption of technologies. The food sector faces substantial obstacles in completely transforming its SC. Especially in the Pakistan market, where economic and technological barriers play a key role (Haddud et al., 2017). Despite all this, the DT remains important for improving efficiency and cost reduction (Jagtap et al., 2019).

So far, no empirical study has explicitly investigated and examined the DT barriers in Pakistan's PFSC. The current literature in Pakistan has focused mainly on textile (Nazam et al., 2022), logistics (Alam et al., 2025), finance (Nadeem et al., 2024), and healthcare (Shoukat et al., 2023) sectors. On the other hand, the food sector has received minimal attention (Dong et al., 2023). This study fills the gap by identifying and analyzing DT barriers in the Pakistan PFSC using TISM and Fuzzy-MICMAC.

This research makes three levels of contribution: contextual, methodological, and theoretical. First, this study identified and examined barriers in Pakistan's PFSC. Second, the integrated TISM and Fuzzy-MICMAC approach develops a hierarchical model through analysis of interrelationships

among barriers. Third, the established hierarchical model offers insight that extends to other developing economies.

The research addresses three questions:

RQ1. What are the major barriers to DT in PFSC?

RQ2. How often are these barriers related to each other?

RQ3. What is the arrangement of identified barriers according to dependence and driving powers?

The rest of the paper is organized in the following manner. Section 2 discusses the literature review. Section 3 provides the research methodology, including TISM and Fuzzy-MICMAC. Section 4 presents results. Section 5 in details discuss the results. The theoretical and managerial implications are discussed in Section 6. Sections 7 and 8 present the conclusion, limitations, and future recommendations, respectively.

2 LITERATURE REVIEW

The challenges associated with Pakistan PFSC are poor IT infrastructure, insufficient logistics, and technological constraints. These issues contribute to food waste and losses (Abbate et al., 2023). The synergic effect of the mentioned challenges results in dipping profitability and creating environmental implications (Ghadge et al., 2020). These issues have slowed down the efforts toward digitalization. This increases the necessity to embrace emerging technologies to remain sustainable and competitive (Qureshi et al., 2023). The DT benefits associates enhanced scalability, speed, traceability, product authentication, and inventory management (Sathiya et al., 2024). Emerging technologies are the foundation of DT and have the ability to transform the PFSC.

The digitalization of the PFSC is necessary in today's volatile and complex business world. Digitalization is a global concern that contributes to green policies by minimizing greenhouse gas emissions and improving digital literacy (Uzule and Verina, 2023). Nonetheless, implementing new technologies is not an ordinary task. The DT process is limited by various barriers (Tavana et al., 2022). Hence, the desired outcomes could be achieved by eliminating these barriers. The following section explains the key barriers.

2.1. Technological Barriers

Several important barriers, such as a complex framework, data heterogeneity, poor IT infrastructure, limited scalability, security, and privacy issues, fall under the technological classification. The lack of a reference framework for DT prevents organizations from embracing digital technologies (Perçin, 2023), which further affects data heterogeneity. The complex and extensive network of FSC aggravates these barriers (Kandasamy et al., 2023). Besides, an absence of a globally accepted set of standards and protocols makes DT more complicated. Moreover, the inflowing heterogeneous data from farmers, processing organizations, transporters, wholesalers, and retailers adds further issues for integrating and managing data (Kumar et al., 2024).

If not handled appropriately, the high volume of data from interconnected sources might be challenging. Managing diverse datasets remains a fundamental issue in implementing digital technologies (Khan et al., 2023). The absence of a systematic knowledge structure, internet access, and smart metering infrastructure limits the adoption of technology (Gupta and Jagtap, 2024). Data flow on the affected IT infrastructure exposes the network to data theft and unauthorized access that may disrupt the SC operations (Chavalala et al., 2022). Studies show that compromised networks worsen security and privacy concerns for all interconnected systems (Agrawal et al., 2020).

Limited scalability has also become a significant problem. Past research deemed scalability as a recognized barrier (Kandasamy et al., 2023). Scalability concern aggravates when organizations are intertwined with fragile IT infrastructure and nonhomogeneous data. Collectively, the absence of an accepted framework, data heterogeneity, inadequate IT infrastructure, security and privacy concerns, and limited scalability are all barriers to the DT process (Perçin, 2023).

2.2. Organizational Barriers

The effect of organizational barriers is equally important, as it dictates how efficiently other technologies can be adopted. Barriers under the organizational category are a lack of support, a lack of reward and recognition, insufficient training and education, a lack of skilled personnel, resistance to change, and a lack of suitable research partners. Lack of training results in a dearth of skilled staff who ignite resistance to change (Alieva and Powell, 2023). Likewise, employee participation is deterred by a lack of a transparent award and reward system, thus weakening organizational preparedness. The successful and sustainable DT program requires managerial backing and a clear way forward (Agrawal et al., 2020).

The managerial support is not sufficient in the case of demotivated employees. Employee engagement and a transparent acknowledgment system maintain employee participation in DT endeavors (Alieva and Powell, 2023). The absence of a reward and recognition system results in digital waste through non-value-adding activity (Khayyam et al., 2022). Insufficient upper management support alongside a lack of a reward and recognition system constitutes a hurdle among employees who are unfamiliar with new technologies (Chavalala et al., 2022). A dynamic system of incentivization and employee engagement can eventually transform organizational culture (Agrawal et al., 2020).

Training and education constitute important elements of organizational readiness. Lack of training and learning opportunities results in a skill shortage. Both technical and managerial skills can be obtained through periodic training sessions (Gupta et al., 2022). Such skills are necessary for data mining, interoperability, and data interpretation, which are aligned with organizational goals (Annosi et al., 2021). Another study highlights the necessity of acquiring new skills to work with complex systems (Gupta and Jagtap, 2024). The absence of expertise hinders the DT process, which links to broader organizational constraints.

Digital transformation programs usually face resistance despite attempts to build skills. The resistance to change is being supported by a fear of being replaced by technology and an unwillingness to abandon traditional processes (Kumar et al., 2021b). Not adopting an ex-ante approach further intensified the failure of DT initiatives in the Pakistan food sector (Khayyam et al., 2022). Managing such initiatives is challenging, as nearly one out of six change efforts fail. Effective management for a successful DT process requires strategic planning and strong leadership (Jones et al., 2021).

The paucity of strategic research alliance worsen resistance to change, considering the market of Pakistan. Robust collaboration among private sectors, institutional stakeholders, and a supportive organizational environment guarantee successful DT initiative (Kumar et al., 2024). All these aspects have a direct effect on limiting the absorptive capacity (Abourokbah et al., 2023). Absorptive capacity is defined as a firm-based approach to acquire and circulate valuable data, enhancing SC performance, and supporting the effective implementation of digital innovations (Javed et al., 2025). Organizations that support collaboration and absorptive capacity are well-positioned to adopt digital solutions and remain competitive (Huma et al., 2024).

2.3. Environmental Barriers

Some of the environmental barriers include the absence of regulatory standards, lack of trust, and supplier scarcity. Digital solutions are needed to improve organizational performance. However, their implementation is hindered by the lack of regulatory standards (Gromova et al., 2022). Such loopholes are seen as institutional voids, where weak regulation and policies impede the digitalization process. Institutional voids are perceived as a gap in formal or informal rules, norms, and enforcement mechanisms, which may have a great influence on growth and innovation (Silvestre, 2015).

The lack of trust turns out to be a critical environmental barrier alongside others. The insufficient trust among stakeholders is cited as the main factor for the non-adoption of digital initiatives according to (Perçin, 2023). These findings are also evidenced by (Agrawal et al., 2020), which also confirms the importance of managerial and financial support in driving DT.

The availability of trusted technical service providers is key to the successful implementation of digital technologies. The swift technological advancement has complicated finding a suitable DT vendor. This issue is not only happening in developing nations, but also in developed economies (Khan et al., 2023). The proper selection of technological partners is vital as their active participation plays a crucial role in long-term sustainability.

2.4. Economic and Financial Barriers

The implementation of developing technologies is restricted by high investment, maintenance costs, and unclear ROI. Implementing advanced technologies necessitates resource requirements, e.g., financial resources and technical skills. These requirements are intensified by expensive smart devices, training, and maintenance. These are required to provide the workforce with the expertise to use digital technologies (Annosi et al., 2021).

The high investment is signaled as the leading barrier to DT in the emerging market (Kumar et al., 2024). Investors and decision-makers remain uncertain over long term benefits of rapidly evolving technologies (Kandasamy et al., 2023). High maintenance costs and doubtful payback make break-even on investment difficult. This financial barrier demotivates organizations from making long-term commitments. Table 1 lists the identified barriers relevant to this research.

Table 1 - Key barriers to DT in PFSC

| Category | Barriers | References |
|-------------------------------|--|---|
| Technological | Complex framework (B1) | (Perçin, 2023, Chavalala <i>et al.</i> , 2022) |
| | Data heterogeneity (B2) | (Perçin, 2023, Khan <i>et al.</i> , 2023) |
| | Poor IT infrastructure (B3) | (dos Santos Silva <i>et al.</i> , 2024) |
| | Security & privacy issues (B4) | (Gromova <i>et al.</i> , 2022) |
| | Limited Scalability (B5) | (Gupta and Jagtap, 2024) |
| Organizational | Lack of support (B6) | (Gupta <i>et al.</i> , 2022) |
| | Lack of rewards and recognition (B7) | (Gupta <i>et al.</i> , 2022, Kumar <i>et al.</i> , 2021b) |
| | Insufficient training and education (B8) | (Perçin, 2023) |
| | Lack of skilled personnel (B9) | (Kumar <i>et al.</i> , 2021b) |
| | Resistance to change (B10) | (Jones <i>et al.</i> , 2021) |
| | Lack of suitable research partner (B11) | (Gupta <i>et al.</i> , 2022) |
| Environmental | Lack of regulatory standards (B12) | (Kumar <i>et al.</i> , 2024) |
| | Lack of trust (B13) | (Khan <i>et al.</i> , 2023, Gupta <i>et al.</i> , 2022) |
| | Supplier scarcity (B14) | (Khan <i>et al.</i> , 2023, Chavalala <i>et al.</i> , 2022) |
| Economic and Financial | Affordability (B15) | (Khan <i>et al.</i> , 2023) |
| | High investment and maintenance costs (B16) | (Annosi <i>et al.</i> , 2021) |
| | Unclear economic benefit of digital investment (B17) | (Chavalala <i>et al.</i> , 2022) |
| | Low awareness of technology and its benefits (B18) | (Kandasamy <i>et al.</i> , 2023) |

2.5. Comparative Insight from Emerging Economies

Though several studies have been conducted to determine the DT barriers in emerging markets. Their findings demonstrate differences in the pattern of barriers. As an example, research in India identified cultural resistance as the most prominent barrier to adopting smart technologies in urban agriculture systems (Srinivasan and Yadav, 2023). Another study centered on the Indian agricultural SC underlined unsupportive government, inadequate incentive system, and institutional voids as significant barriers to the Industry 4.0 application implementation (Kumar *et al.*, 2021b). Further studies indicate that poor governance, transparency, and immutability play a critical role in disrupting blockchain adoption (Ghode *et al.*, 2020).

The Bangladesh manufacturing sector highlights lack of technical knowledge, insufficient skills, and low staff morale are leading causes to the adoption of Industry 4.0 applications (Hossain *et al.*, 2023). Comparatively, the studies in Pakistan present different results. According to (Alam *et al.*, 2025), the Pakistan courier supply chain DT process is disrupted by obscured goals. The finance and textile sector reports inadequate ICT infrastructure and technological immaturity as DT barriers (Nadeem *et al.*, 2024, Nazam *et al.*, 2022).

3 METHODOLOGY

The PRISMA methodology was used in this study to facilitate transparency and rigor in the literature review process (Moher *et al.*, 2015). PRISMA technique is commonly used in systematic literature reviews by eradicating bias through predefined protocols (Akomea-Frimpong *et al.*, 2023).

Such reviews synthesize previous research, determine gaps, and guide future studies. PRISMA guarantees concise inclusion-exclusion standards and reproducibility in comparison to bibliometric analysis (Pakdel and Erol, 2025). Fig.1 depicts the research framework. This study followed three stages similar to (Butler et al., 2020, Regona et al., 2022).

Stage 1 (Planning): The research starts with defining research questions and choosing relevant literature keywords for a search. The articles published until 2024 in peer-reviewed journals were searched from different databases. A total of 81 articles related to DT were selected out of a first set of 585.

Stage 2 (Performing review): The inclusion criteria include peer-reviewed, English-language, and relevant studies that match the research objectives. The exclusion criteria consists industrial reports, book chapters, magazines, irrelevant papers, and duplicate articles.

Stage 3 (Reporting and Expert input):

Eleven other studies were included following suitability with the research objectives. Industry and academic experts were interviewed semi-structuredly to validate and narrow down the barriers. A purposive sampling method was adopted for expert selection (Bamel and Bamel, 2021). The inclusion criteria for participants require occupying a managerial position, managing FSC operations, DT projects association, and having a relevant academic qualification. The selected respondents possessed an average of 15 years of work experience. This resulted in a panel comprising middle management (72%), senior management (14%), and junior management (14%) (See Table 2). The expert insight and PRISMA integration further refined the DT barrier to reflect the theoretical rigor and practical realities. There were nineteen barriers initially identified, at first, and 18 were considered after expert validation and refinement.

Table 2 - Demographics of the Participants

| S.No | Demographic Details | Description | Number |
|------|-------------------------------|-----------------------------------|--------|
| 1 | Experience | 5—10 | 2 |
| | | 11—15 | 3 |
| | | 16—20 | 1 |
| | | Above 20 | 1 |
| 2 | Educational Qualification | PhD | 2 |
| | | MSc/MBA | 4 |
| | | BSc | 1 |
| 3 | Nature of Business Activities | Academics | 3 |
| | | Perishable Food Industry | 1 |
| | | Food Department (Govt. officials) | 2 |
| | | Retail Supply Chain | 1 |

The technique of fixed sample size is not fit in-case of TISM (dos Santos Silva et al., 2024). The panel of seven participants was considered for this research. Some prior studies selected 5-10 participants for similar modeling (Jena et al., 2017, Thakur, 2021). All interviews were conducted face-to-face. Each interaction ranged from approximately 40 to 60 minutes. The interviews started with open-ended questions and then concluded with closed-ended questions. The panel was made up of both industry and academic experts to capture various perspectives. Differences in opinion were also deliberated among field experts. A consensus was reached, which helps reduce bias in the final model. This was followed by the development of a contextual relationship matrix to explore the hierarchical relationships among barriers. The TISM model and Fuzzy-MICMAC analysis were performed in Microsoft Excel. The graphical output was generated using Microsoft Visio.

3.1 Total Interpretive Structural Modeling (TISM)

ISM is a systematic approach coined by Warfield, helping experts in investigating complex interrelations and establishing a hierarchical model (Nayal et al., 2021b). It is a participatory learning process that combines various elements into a comprehensive and systematic model (Hassan et al., 2021). A few of the shortcomings associated with ISM are personal bias, lack of statistical validation, and increased complexity as the number of elements grows (Attri et al., 2013).

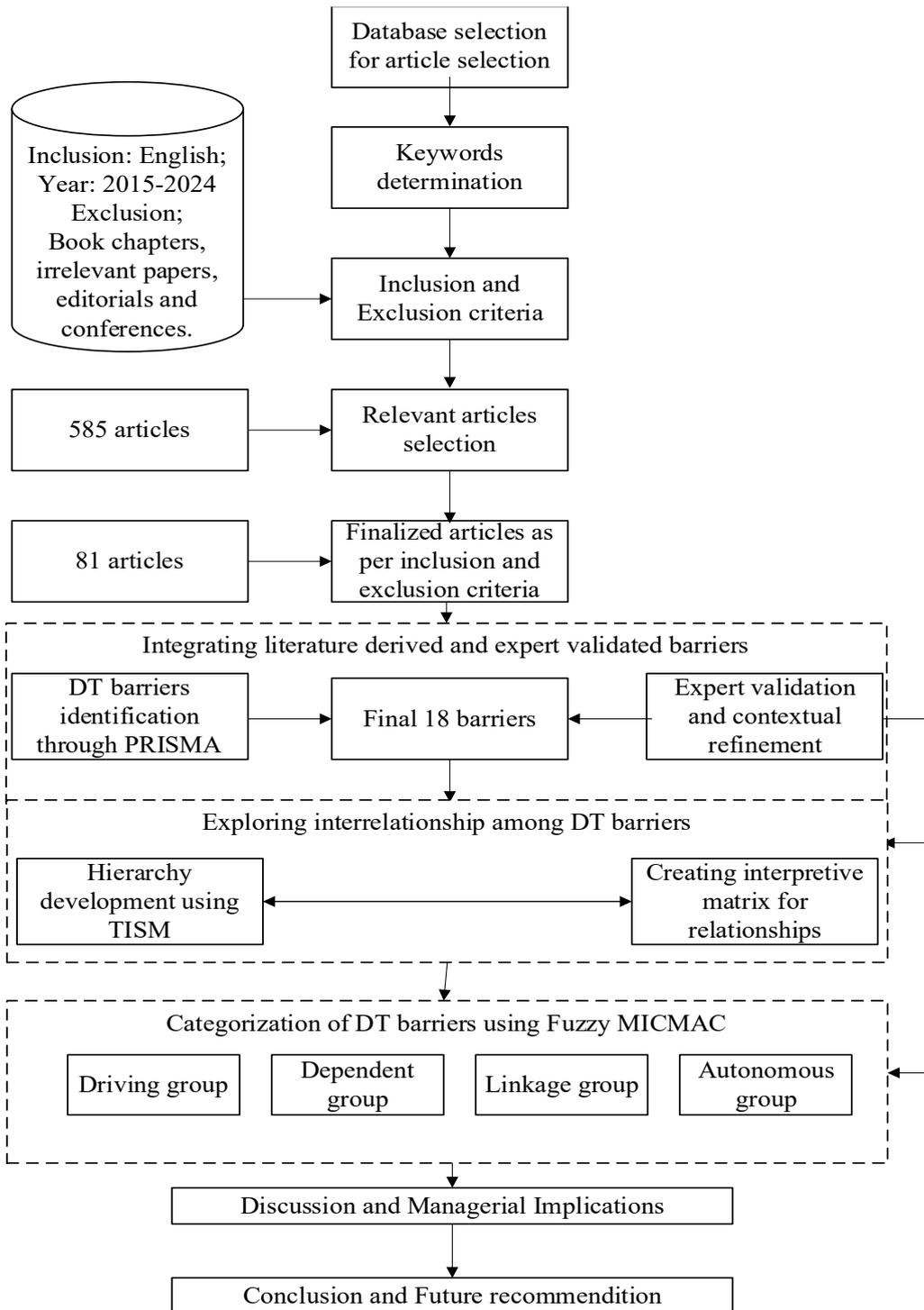


Figure 1 - Research methodology framework depicting the combination of PRISMA-based systematic barrier identification and expert validation leading to the TISM-Fuzzy MICMAC model

Several hybrid approaches have emerged to address these limitations. For example, ISM-DEMATEL maps cause-effect linkages but lacks interpretive depth (Ahmad et al., 2024); ISM-ANP assigns weights rather than interpretive interactions (Kumar et al., 2021b), and ISM-TOPSIS ranks alternatives through MCDM without capturing the underlying reasons among barriers (Al Amin et al., 2023).

In contrast, TISM (a revised version of ISM) develops an interpretive hierarchical model through an iterative process (Hasan et al., 2019). To further address uncertainty in expert judgments, Fuzzy MICMAC was integrated with TISM. The integrated approach produces systematically organized models from ambiguous inputs (Nadeem et al., 2024). Considering the synergic effect, TISM-Fuzzy

MICMAC was considered the appropriate approach for this study. The following steps are included in the TISM approach (Thakur, 2021, Hasan et al., 2019, Jena et al., 2017, Bohtan et al., 2017).

Barriers Identification and Definition

The literature review and expert interviews led to the identification of eighteen barriers, including technological, environmental, organizational, and economical. These barriers are listed in Table 1.

Define Contextual Relationship

Expert feedback was used to establish the contextual relationships. For each pair of barriers, A yes/no relationship between barriers was established to show whether one barrier influences the other or not.

Contextual Relationship and Pairwise Comparison Interpretation

The study involved pair-wise comparisons to determine the effect of every barrier on the rest to obtain a relationship matrix. This matrix serves as the foundation for subsequent analyses.

Final Reachability Matrix

The reachability matrix is developed by assigning 1 to each cell in the interpretive knowledge base that includes “YES” and 0 to cells that contain “NO”. The reachability matrix then undergoes the transitivity theory. The transitivity theory states that if A is linked to B and B is linked to C, then C is linked to A. Following the transitivity rule, entries in the reachability replaced with 1*. The transitivity check is repeated until transitivity is achieved. After the transitivity check, the final reachability matrix is produced. The final reachability matrix is shown in Table A.1.

Level Partitioning

Level partitioning of the final reachability matrix is performed to determine the position of barriers. The structured model hierarchy is obtained by level partitioning of the final reachability matrix. The reachability matrix includes the reachability set and antecedent set. The reachability set includes the element itself and other elements it may impact. Whereas, the antecedent set includes the element itself and other elements that may be affected by it. The intersection set is derived from the reachability and antecedent sets. The barrier having the same set of reachability and intersection set is positioned at the top level. After identifying the barrier at the top level, it was detached from the other barriers. Hence, the barriers, such as B11, B14, B15, and B18, are found at level I (Table 4) and are eliminated. To determine barriers at subsequent levels, the same process is continued until the level of each barrier is achieved.

Table 4 - Reachability and Antecedent sets (Iteration 1-6)

| Barriers | Reachability Set | Antecedent Set | Interaction Set | Levels |
|----------|--|---|--|--------|
| B1 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,9,10,11,1,2,13,14,15,16,18 | 1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,18 | III |
| B2 | 2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,5,6,7,8,9,10,11,1,2,13,14,15,16,17 | 2,3,4,5,6,8,9,10,11,12,13,14,15,16,17 | III |
| B3 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,9,11,12,13,14,15,16, | 1,2,3,4,5,6,9,10,11,12,13,14,15,16,17 | V |
| B4 | 2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18 | 2,4,5,6,7,8,9,10,11,12,13,15,16,17,18 | II |
| B5 | 2,3,4,5,6,7,8,9,10,11,12,13,14,16,15,18 | 2,3,4,5,6,7,8,9,10,11,1,2,13,14,16,15,17 | 2,3,4,5,6,7,8,9,10,11,12,13,14,15,16 | III |
| B6 | 1,2,3,4,5,6,7,8,9,10,11,12,14,15,17 | 1,2,3,4,6,7,9,11,12,14,17 | 1,2,3,4,6,7,9,11,12,13,14,17 | VI |
| B7 | 2,3,4,5,7,8,9,10,13,14,15,16,17,18 | 1,2,3,5,7,8,10,11,12,13,15,16,17 | 2,3,5,7,8,10,13,15,16,17 | V |
| B8 | 2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18 | 2,3,4,5,6,7,8,9,10,11,13,15,16,17,18 | II |
| B9 | 1,2,3,4,5,6,7,9,10,11,12,13,14,16,15,17,18 | 1,2,3,4,5,6,7,9,10,11,1,2,13,14,15,16,17,18 | 1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17,18 | II |

| | | | | |
|-----|--|--|--|-----|
| B10 | 1,2,3,4,5,6,7,8,9,10,11,13,14,16,15,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,14,15,16,17,18 | II |
| B11 | 1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17,18 | I |
| B12 | 2,5,6,7,9,10,11,14,15,17,18 | 2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,3,4,5,6,7,9,10,11,14,15,17,18 | II |
| B13 | 1,2,3,4,5,6,7,8,9,10,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,15,17,18 | 1,2,3,4,5,6,7,8,9,10,13,15,17,18 | III |
| B14 | 1,2,3,4,5,6,7,9,11,12,13,14,16,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,9,11,12,13,14,16,17 | I |
| B15 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | I |
| B16 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,6,7,8,9,10,11,12,13,14,16,17 | 1,2,3,4,6,7,8,9,10,11,12,13,14,16,17 | IV |
| B17 | 1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17 | 1,2,3,4,5,6,7,9,10,11,12,13,14,15,16,17 | II |
| B18 | 2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | 2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18 | I |

Developing Digraph

A digraph or directed graph depicts the interrelationships among the DT barriers based on the levels assigned to them. Level partitioning creates a digraph of direct and critical transitive links derived from the final reachability matrix. The TISM model only includes diagrams with significant transitive relationships for interpretation purposes. It implies that B11, B14, B15, and B18 are positioned at level I. Moving on, B4, B8, B9, B10, B12, and B17 are placed at level-II. Similarly, B1, B2, B5, and B13 are assigned at level III. Furthermore, B16 is positioned at level IV. Additionally, B3 and B7 are placed at level V. Lastly, B6 is assigned at level VI. Figure 2 depicts the digraph with significant transitive relationships.

The TISM model illustrates relationships through inputs like “1” (a relationship exists) and “0” (no relationship). It equally weights both transitive and intransitive links irrespective of their strength (Shamsuzzoha and Piya, 2020). The Fuzzy-MICMAC approach in such cases is applied to incorporate sensitivity in analysis (Thakur, 2021). The steps below show the Fuzzy-MICMAC procedure.

Binary Direct Relation Matrix (BDRM)

The diagonal entries of the final reachability matrix are changed to zero in BDRM. Transitive links are ignored in this step.

Fuzzy Direct Relation Matrix (FDRM)

Fuzzy Set Theory is employed to enhance the sensitivity of MICMAC analysis, which typically use only binary integers. The expert inputs on the strength of relationships among various barriers are defined on a fuzzy scale from 0 to 1 (0 = no effect, 0.1 = negligible effect, 0.3 = low effect, 0.5 = medium effect, 0.7 = high effect, 0.9 = very high effect, 1 = full effect). The FDRM is obtained by replacing all binary relationships in the BDRM matrix with fuzzy values.

Stabilized Fuzzy Matrix

In this process, the FDRM is multiplied iteratively until the driving and dependence powers of the barriers stabilized. According to fuzzy set theory, multiplying fuzzy matrices always produces another fuzzy matrix, keeping the analysis fuzzy in nature (Agrawal *et al.*, 2020). Eq. 1 was used for iterative multiplication;

$$A \times B = \max(\min(a_{lm}, b_{mn})) \tag{1}$$

Where, A = a_{lm}, and B = b_{mn}.

4 RESULTS

The Fuzzy-MICMAC analysis (Figure 4) was applied to categorize the DT barriers by mapping their driving and dependence power. The analysis categorizes barriers into four quadrants: autonomous, dependent, linkage, and independent. The Fuzzy-MICMAC approach develops a driving-dependence power diagram that shows the relative importance and the interrelationship between barriers. This Fuzzy-MICMAC analysis categorizes barriers into four quadrants: autonomous, dependent, linkage, and independent.

The first quadrant contains the autonomous barriers. Due to low driving and dependence power, the autonomous quadrant factors are considered the least influential and affect the system minimally (Thakur and Anbanandam, 2016). In this study, no autonomous barriers were identified. However, if present, they have to be treated as driving barriers.

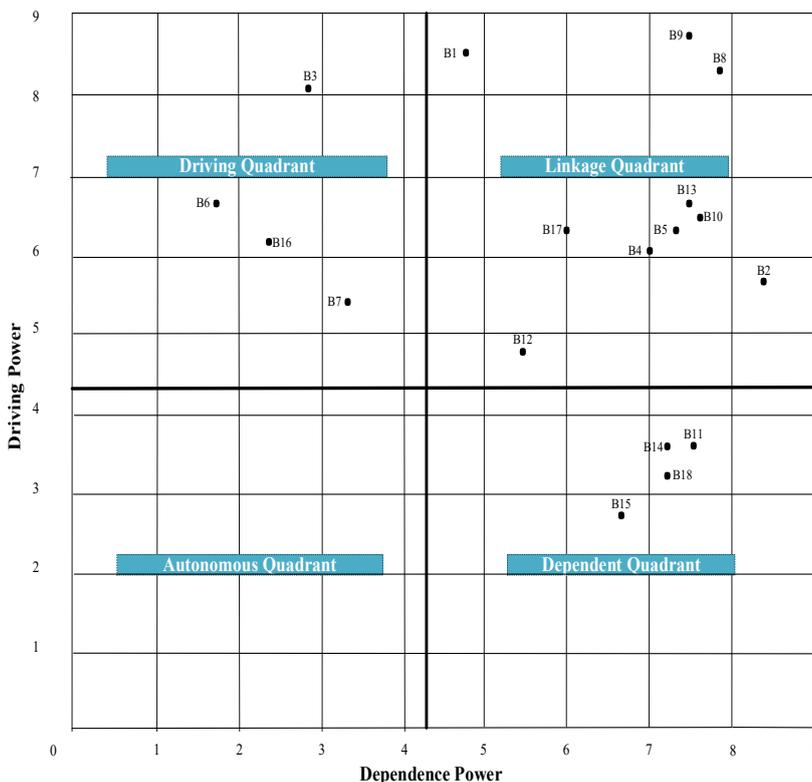


Figure 3 - Driving and dependence power diagram

Quadrant 2nd (Dependent Quadrant): Affordability, Low Awareness of Technology and its Benefits, Lack of suitable research partners, and Supplier Scarcity come into the dependent quadrant. These barriers exhibit low driving but high dependence power, making them highly influenced by other barriers (dos Santos Silva *et al.*, 2024). The dependent quadrant barriers highlight the effect of other issues.

Quadrant 3rd (Linkage Quadrant): Unclear Economic Benefits of Digital Investment, Lack of Skilled Personnel, Resistance to Change, Insufficient Training and Education, Complex Framework, Data Heterogeneity, Security and Privacy Issues, Limited scalability, Lack of Trust, and Lack of Regulatory Standards fall in the third quadrant. Linkage quadrant barriers are critical as they balance the system. Linkage quadrant variables have high influence and dependence on other variables (Mishra *et al.*, 2023).

Quadrant 4th (Driving Quadrant): Lack of support, High Investment and Maintenance Costs, Lack of Reward and Recognition, and Poor IT infrastructure are placed in the fourth quadrant. Driving quadrant barriers pose a higher driving compared to other quadrants, making it the most influential quadrant (dos Santos Silva *et al.*, 2024). These barriers are considered the primary source of disturbance and have to be given top priority. The driving quadrant barriers overlap with the foundational levels of the TISM model, clearly serving as root causes and making them a priority for both managers and policymakers.

5 DISCUSSIONS

The present study aimed to identify DT barriers in the Pakistan PFSC, develop a hierarchy, and examine their driving-dependence relationship using TISM-Fuzzy MICMAC. A list of barriers was derived from the literature and validated by experts from industry and academia. These experts assessed relationships among barriers. The collected data were then analyzed using the TISM-Fuzzy MICMAC approach.

Findings suggest that the following barriers, including low awareness of technology and its benefits, affordability, a lack of suitable research partners, and supplier scarcity, are positioned at the top layer of the hierarchy. These barriers are largely dependent on foundational barriers. Prior studies also recognize them as secondary barriers. For example, (Khan *et al.*, 2023) concluded that low awareness, financial challenges, lack of collaborative efforts with research institutes, and limited service providers discourage the emerging technologies adoption. Another study found that government-led financial support and awareness campaigns are necessary for PFSC digitalization (Kumar *et al.*, 2021b). Strategic partnerships with research institutions and awareness campaigns influence the adoption of emerging technologies.

Level-2 (Figure 3) includes six barriers: unclear economic benefits of digital investment, a lack of skilled personnel, resistance to change, insufficient training and education, security and privacy issues, and a lack of regulatory standards. These barriers exert greater influence than Level-1. For instance, unclear ROI discourages investment and undermines skill development (Chavalala *et al.*, 2022, dos Santos Silva *et al.*, 2024). Similarly, (Perçin, 2023) confirmed that the training gap and change resistance hinder the spread of digital practices. Moreover, inadequate regulation further exposes the system to cyberattacks and hacking, creating security and privacy concerns (Shoukat *et al.*, 2023). The effect of these barriers on the successful adoption can only be diminished when foundational-level barriers are addressed.

Level-3, includes six barriers: complex framework, data heterogeneity, limited scalability, and lack of trust. In the global context, the absence of a reference framework is considered a major concern for DT (Khan *et al.*, 2023). This concern is also critical in Pakistan, where the fragmented implementation of digital technologies leads to limited scalability (Sun *et al.*, 2024). Additionally, heterogeneous data results in inconsistent outcomes during DT (Annosi *et al.*, 2021). Regarding data security and misuse in emerging countries, trust is identified as the most critical barrier to the smooth DT (Perçin, 2023, Chavalala *et al.*, 2022).

High investment and maintenance cost is positioned at Level-4. Adopting emerging technologies requires significant investment and maintenance costs (Gupta *et al.*, 2022). Financial pressure specifically limits SMEs' DT initiatives. Prior studies reported similar findings in developing nations (Khan *et al.*, 2023). In addition, SMEs find it difficult to get government subsidies, trade credit, and SC finance. These mechanisms can make a substantial impact by alleviating cash-flow concerns and allowing organizations to invest in emerging technologies. Lacking financial support, businesses depend on their limited resources, which limits the DT efforts.

Level-5 of the TISM model includes Poor IT infrastructure and a lack of reward and recognition. Pakistan weak digital infrastructure is reported as the leading challenge to technology adoption (Nadeem *et al.*, 2024). These findings align with the Indian context (Khan *et al.*, 2023, Gupta *et al.*, 2022). Connectivity issues are particularly severe due to uneven digital access between rural and urban areas. Furthermore, the absence of a reward and recognition system affects employee

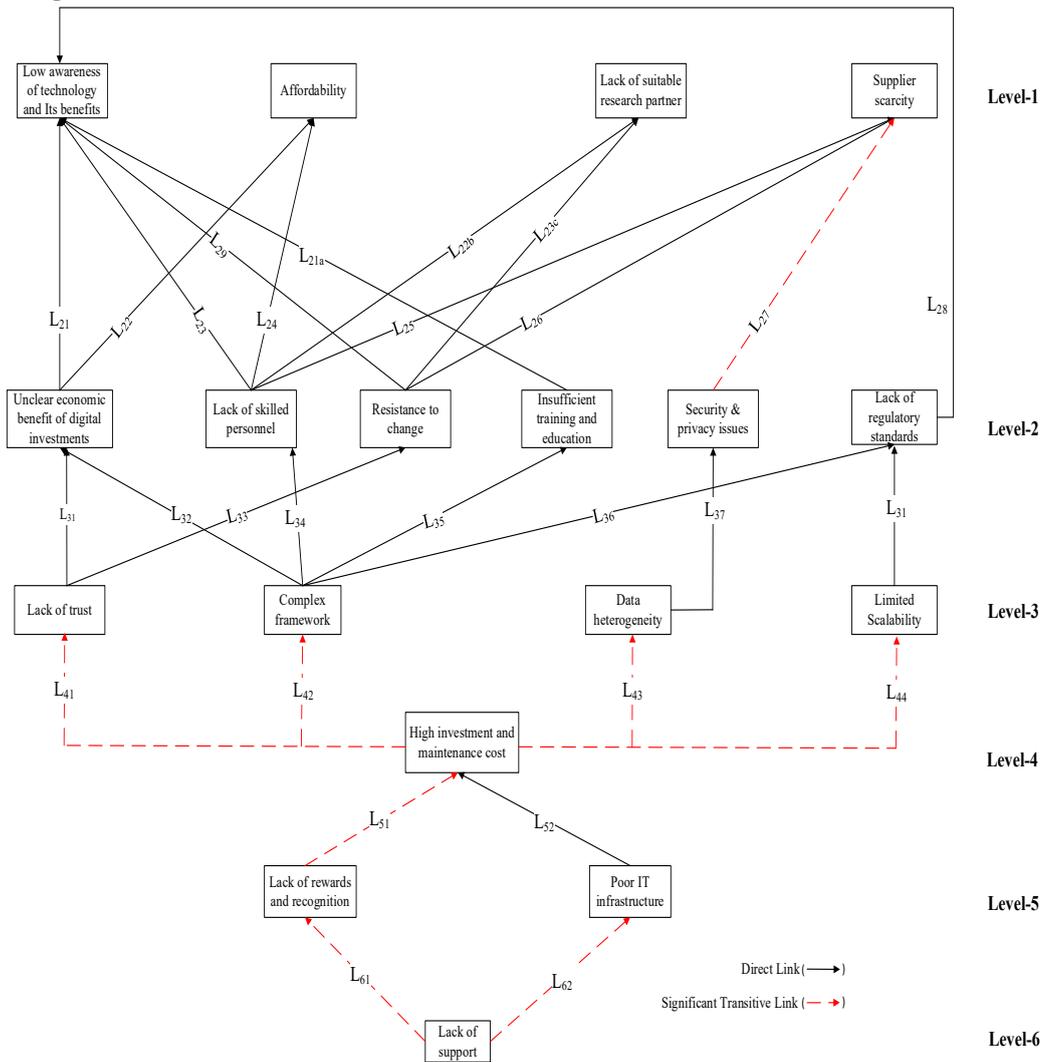
motivation (Gupta *et al.*, 2022). Together, these barriers represent technological and organizational challenges that obstruct PFSC digitalization.

In conclusion, the last level is formed by a barrier: Lack of support. This is a significant barrier that stands as a wall to the adoption of emerging technologies and DT in Pakistan PFSC. According to (Perçin, 2023), lack of support is the most critical organizational barrier. It directly drives upper-level barriers in the hierarchy. These results distinguish Pakistan from Bangladesh and India, where technical knowledge (Hossain *et al.*, 2023) and cultural resistance (Srinivasan and Yadav, 2023) are considered critical. However, in Pakistan, inadequate financial and managerial support emerges as the most driving barrier for DT.

Studies from India and Bangladesh highlight that cultural resistance, lack of support, and insufficient technical knowledge-related issues often occupy a high driving barrier to DT. By contrast, in the Pakistani context, the dominant barriers are insufficient support, lack of rewards and recognition, high investment and maintenance costs, and poor IT infrastructure. This divergence shows that DT cannot be generalized, and that country-specific dynamics must be taken into account when studying emerging economies.

These barrier effects are further exacerbated by Pakistan FSC perishable nature. An unreliable cold-chain network and product short shelf life lead to issues such as inadequate support, lack of trust, and intricate/poor IT infrastructure. A small delay or miscommunication can cause spoilage and financial loss. Recent events such as the COVID-19 pandemic, geopolitical tensions, and changing climate patterns further complicate the DT adoption. These unexpected shocks exposed system flaws and necessitate the need for transparency and flexibility. In a developing context like Pakistan, these disruptions often intensify existing constraints and slow digital adoption.

Figure 4 - TISM model for PFSC DT barriers



6 IMPLICATIONS

6.1 Theoretical Implications

This research provides multi-fold theoretical contributions to the knowledge on digital transformation barriers in Pakistan's PFSC. This study also provides a conceptual framework adaptable to DT ecosystems. First, it is the first study to identify and investigate DT barriers within the Pakistan PFSC. Second, this study employed the TISM-Fuzzy MICMAC approach to establish the contextual relationships among identified barriers. To date, no available research has studied the interrelationship between Pakistan's PFSC using a novel technique such as TISM-Fuzzy-MICMAC. This approach enables the categorization of barriers into autonomous, independent, dependent, and linkage quadrants, thereby clarifying their nature.

Moreover, barriers such as inadequate support and a weak incentive system align with upper echelons theory, which states that organizational strategies and innovation outcomes are shaped by the values and characteristics of upper management. This highlights the upper management support in overcoming DT barriers in the Pakistan PFSC. Concluding, this study extends the literature by offering a combined perspective on technological, organizational, environmental, and economic factors that jointly influence DT in emerging economies.

6.2. Managerial Implications

This study offers an important perspective into the DT barriers for field professionals. The study considers lack of support as a leading barrier. The management and concerned experts should consider eliminating these barriers by providing both ethical backing and sufficient resources to ensure seamless implementation of emerging technologies (Kandasamy et al., 2023).

The findings also show that poor IT infrastructure, lack of rewards and recognition prevailed as the secondary leading barriers. Employee training, collaboration with businesses, and developing skill sets are preferred to promote DT initiatives (Mathivathanan et al., 2021). The process of implementing digital technologies requires numerous efforts. Businesses should compensate individuals involved in DT efforts through a transparent rewards and recognition system. The proposed model offers field experts a hierarchy and categorization of DT barriers. SC experts can eliminate these obstacles by examining each barrier and offering suitable strategies.

The digital infrastructure can be improved via public-private partnerships and risk-sharing investments with the government or donor agencies. More initiatives, including capacity-building, can further enhance workforce preparedness. Other factors, such as tax relief and financial subsidies, may also be considered drivers for adopting digital transition.

7 CONCLUSION

The efficient SC activities require digitalization. The need to adopt digital technologies in SC is more than ever. However, various barriers complicate SC digitalization. This study identified those barriers and modeled their interrelationship in the context of Pakistan PFSC. Barriers were identified using a systematic literature review and were subsequently validated through expert input. A hybrid technique of TISM and Fuzzy-MICMAC was adopted to determine the interrelationship. The TISM model was found to be useful in transforming the data into a structured model. The results indicated six levels of interconnected barriers. Further, Fuzzy-MICMAC further validated the TISM findings by categorizing them into four quadrants.

This research explicitly addresses the research questions by identifying the DT barriers (RQ-1), interrelationship analysis (RQ-2), and barriers categorization (RQ-3). The levels in the TISM model demonstrate that foundational-level barriers influence upper-level barriers by offering contextual insight (RQ-2). In addition, Fuzzy-MICMAC four quadrants confirm barriers priority and systematic influence (RQ-3).

The findings suggest that the most noticeable barriers to DT are a lack of support, high investment and maintenance costs, a lack of reward and recognition, and poor IT infrastructure. Overcoming these barriers could have a ripple effect on the DT process. These findings can help PFSC experts and policymakers in designing strategies and enabling seamless DT.

8 LIMITATIONS, FUTURE DIRECTIONS, AND ORIGINALITY

The study limitations merit discussion. First, the scope of applicability is limited to the Pakistan PFSC. Second, the TISM analysis was established based on perspectives from literature, academia, and industry professionals. The small size and purposive sampling technique may influence expert bias, as individual experience or beliefs could shape the interpretation. Therefore, the final results

may be affected by individual beliefs. Third, TISM structures the interrelationships among variables. However, it does not assign weights, which makes the situation difficult for decision-makers to set a clear goal or plan resources effectively.

While this research identifies barriers and employs TISM-Fuzzy MICMAC, it lacks quantitative analysis. The impacts of barriers were subjectively assessed, without mathematical quantification or statistical testing. Partial Least Squares Structural Equation Modeling (PLS-SEM) and Analytical Network Method (ANP) can be employed to validate the results. Grey and Fuzzy theories can also be used to address a small sample size and consider the fuzziness of respondents. Other techniques, such as Decision Making Trial and Evaluation Laboratory (DEMATEL), or its hybrid form, D-ANP (DEMATEL-based ANP), could be used to measure the mutual dominance. Such methodological integration could mitigate expert bias and enhance the transparency of findings. Moreover, as the study relies on literature review and expert opinions, it lacks the element of triangulation through a case study or validation at the firm level. Consequently, few interrelationships among barriers may remain theoretical. Future studies could address this by carrying out longitudinal or pilot case studies to validate the model's applicability in the real-world PFSC context. Future research may also expand the scope to other regions and beyond the perishable food sector, such as health and construction etc. The current model presents a static view of how barriers interact with one another. In practice, these relationships may evolve as the DT process advances. Future research could investigate barriers to development and change across different PFSC sub-sectors over time.

The originality of this research lies in integrating TISM and Fuzzy-MICMAC in the context of Pakistan PFSC. The outcomes reflect the situations present in many developing economies. SCs frequently face disarray and inadequate infrastructure in such settings. Even so, the acumen from this research can benefit other emerging economies. However, their particular contexts should always be taken into account when applying the outcomes.

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Appendix A

Table A. 1 Final Reachability Matrix

| | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 | B12 | B13 | B14 | B15 | B16 | B17 | B18 | |
|------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| B1 | 1 | 1 | 1* | 1* | 1 | 1* | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1 | 1* | 1* | 1 | 1* | 18 |
| B2 | 1 | 1 | 1 | 1 | 1 | 0 | 1* | 1* | 1* | 0 | 1* | 1* | 1* | 1* | 1 | 1* | 1* | 1* | 16 |
| B3 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1* | 1 | 18 |
| B4 | 1* | 1 | 1* | 1 | 1* | 0 | 1* | 1 | 1 | 1* | 1* | 1 | 1 | 1* | 1* | 0 | 1* | 1* | 16 |
| B5 | 1 | 1 | 1* | 1* | 1 | 0 | 1* | 1* | 1* | 1* | 1 | 1 | 0 | 1* | 1* | 1 | 1* | 1* | 16 |
| B6 | 1* | 0 | 1* | 1* | 0 | 1 | 1* | 1* | 1* | 1 | 1* | 0 | 1 | 1* | 1 | 1 | 1* | 1 | 15 |
| B7 | 0 | 1* | 0 | 1* | 1* | 0 | 1 | 1* | 0 | 1 | 1* | 1* | 1 | 1 | 1* | 1* | 1 | 1* | 14 |
| B8 | 1* | 1* | 0 | 1 | 1 | 0 | 1* | 1 | 1 | 1 | 1* | 1* | 1 | 1* | 1* | 1* | 1* | 1 | 16 |
| B9 | 1* | 1 | 1* | 1 | 1* | 1* | 0 | 1 | 1 | 1 | 1 | 1* | 1* | 1 | 1 | 1* | 1 | 1 | 17 |
| B10 | 1* | 1* | 0 | 1 | 1* | 1* | 1* | 1 | 1* | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 1* | 1 | 17 |
| B11 | 1* | 1* | 1* | 1* | 1* | 1 | 0 | 1* | 1 | 1* | 1 | 1* | 1* | 1 | 1* | 1 | 1 | 1 | 17 |
| B12 | 1* | 0 | 0 | 1* | 0 | 0 | 0 | 1* | 1* | 1 | 1* | 1 | 1* | 1* | 1* | 0 | 0 | 1 | 11 |
| B13 | 0 | 1* | 0 | 1* | 1* | 1* | 1 | 1* | 1* | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 1 | 1* | 16 |
| B14 | 1* | 1* | 1* | 0 | 1 | 1* | 0 | 0 | 1* | 1* | 1 | 1 | 0 | 1 | 1* | 1 | 1* | 1* | 14 |
| B15 | 1* | 1* | 1 | 1 | 1* | 1* | 1* | 1 | 1* | 1* | 1 | 1* | 1* | 1 | 1 | 1* | 1 | 1 | 18 |
| B16 | 1* | 1* | 1 | 1* | 1* | 1 | 1* | 1* | 1 | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1* | 1* | 18 |
| B17 | 1* | 1 | 1* | 1* | 1 | 1* | 0 | 1* | 1* | 1 | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 1 | 17 |
| B18 | 1 | 1* | 1* | 1 | 1* | 0 | 1* | 1 | 1 | 1 | 1* | 1* | 1 | 1* | 1 | 0 | 1* | 1 | 16 |
| | 16 | 16 | 13 | 17 | 16 | 11 | 13 | 17 | 17 | 17 | 18 | 17 | 16 | 18 | 18 | 15 | 17 | 18 | 290 |

Table A.2 Knowledge Base

| S.No | Pairwise comparison | Reasons |
|------|---|--|
| 1 | How does Lack of support influence/triggers/effect Affordability? | Insufficient upper management support and a restricted budget allocation for modern technologies affects the affordability of adopting and maintaining new system. |
| 2 | How does Lack of support influence/triggers/effect High investment and maintenance cost? | Inadequate support from superiors causing high initial and maintenance cost associated with technology adoption. |
| 3 | How does Lack of support influence/triggers/effect Low awareness of technology and Its benefits? | Poor leadership causes the absence of substantial training programs, which contributes to resistance and a general lack of interest in understanding the benefits of new technology. |
| - | - | - |
| - | - | - |
| - | - | - |
| - | - | - |
| - | - | - |
| - | - | - |
| 112 | How does Lack of trust influence/triggers/effect Supplier scarcity? | Lack of trust hinders IT service providers from taking part in DT activities. |
| 113 | How does Lack of Regulatory Standards influence/triggers/effect Low awareness of technology and Its benefits? | Improper standards creates an uncertain environment for organizations, resulting in uncertainty and ambiguity over technology to implement. |
| 114 | How does Lack of Regulatory Standards influence/triggers/effect Resistance to change? | The lack of explicit regulations creates ambiguity, which leads to increasing resistance to DT. |

Table A.3 Interpretive Matrix

| | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 |
|-----|---|--|--|--|----|--|--|--|---|---|
| B1 | - | | | | | | | Reference framework gap impedes standard training and delays technology adoption | Advanced technology adoption depends on expert skills | |
| B2 | | - | | Diverse data sources weaken security, increasing privacy vulnerabilities | | | | | | |
| B3 | | | - | | | | | | | |
| B4 | | | | - | | | | | | |
| B5 | | | | | - | | | | | |
| B6 | | | Limited support constrains cybersecurity infrastructure. | | | - | Absence of support hinders employee motivation through recognition | | | |
| B7 | | | | | | | - | | | |
| B8 | | | | | | | | - | | |
| B9 | | | | | | | | | - | |
| B10 | | | | | | | | | | - |
| B11 | | | | | | | | | | |
| B12 | | | | | | | | | | |
| B13 | | | | | | | | | | Lapses arise if stakeholders reluctant to share critical information. |
| B14 | | | | | | | | | | |
| B15 | | | | | | | | | | |
| B16 | High expenses limit investment and creation of streamlined framework. | Limited budget hinders unified data management system. | | | | Large-scale digital growth restricts by escalating expenses. | | | | |
| B17 | | | | | | | | | | |
| B18 | | | | | | | | | | |

Table A.3 Interpretive Matrix (Continuous)

| | B11 | B12 | B13 | B14 | B15 | B16 | B17 | B18 |
|-----|---|---|---|---|---|--|---|---|
| B1 | | Unclear reference framework hinders policy design, slowing regulatory development | | | | | Investors' trust undermined by absence of reference framework | |
| B2 | | | | | | | | |
| B3 | | | | | | Weak IT systems lead to frequent and expensive maintenance | | |
| B4 | | | | Security concerns discourage supplier participation in DT process | | | | |
| B5 | | Scalability issues obstruct development of regulatory standards | | | | | | |
| B6 | | | | | | | | |
| B7 | | | | | | Demotivated staff increases inefficiencies, driving up expenses. | | |
| B8 | | | | | | | | Insufficient training limits awareness of technologies |
| B9 | Limited skilled personnel discourage industry-research collaboration. | | | Supplier scarcity results from inadequate technical expertise | Costly errors and rework inflate DT costs | | | Absence of skilled mentors obstructs awareness building. |
| B10 | Reluctance to change discourages research collaboration. | | | Organizational resists service providers' market entry. | | | | Change resistance hinders technological awareness. |
| B11 | - | | | | | | | |
| B12 | | - | | | | | | Ambiguous regulations weaken organizational efforts for DT awareness. |
| B13 | | | - | | | | Distrust obscure digital investment ROI. | |
| B14 | | | | - | | | | |
| B15 | | | | | - | | | |
| B16 | | | Economic limitations undermine trust and increase skepticism. | | | | | |
| B17 | | | | | Uncertain ROI heightens affordability challenges. | | | Unclear payoffs reduce technological benefits. |
| B18 | | | | | | | | - |

Table A.4 Links Interpretation

| Link No. | Link | Interpretation |
|----------|---------|---|
| L61 | B6-B7 | Limited recognition discourages innovation |
| L62 | B6-B3 | Lack of Funding and managerial support hinders the development of a robust IT infrastructure |
| L51 | B7-B16 | Demotivated employees contribute to high maintenance and operational costs |
| L52 | B3-B16 | Lack of a robust IT infrastructure necessitates high maintenance. |
| L41 | B16-B13 | Economic limitations cause investors to distrust. |
| L42 | B16-B1 | High spending on adopting technologies is associated with the absence of a reference framework. |
| L43 | B16-B2 | Manual record keeping and uneven data structure require significant cost to standardize. |
| L44 | B16-B5 | Financial constraints and resource allocation hinder expansion. |
| L31 | B13-B17 | Limited ROI on digital investment makes investors uncertain. |
| L32 | B1-B17 | Uncertain framework undermines investor trust. |
| L33 | B13-B10 | Absence of credibility resists change management. |
| L34 | B1-B9 | Lack of a standardized framework affects the skill set |
| L35 | B1-B8 | Reference framework ensures standardized training, and inadequate training slows down technological development |
| L36 | B1-B12 | A unified reference framework and clear policies lead to a successful DT process |
| L37 | B2-B4 | Diverse data sources weaken the system, leading to cyberattacks |
| L38 | B5-B12 | Fragmented data prevents regulators from implementing a data-driven system |
| L21 | B17-B18 | Restricted economic rewards impede awareness campaigns |
| L22 | B17-B15 | Unclear returns impact funding decision |
| L23 | B9-B18 | Technological awareness limits by the shortage of qualified experts. |
| L24 | B9-B15 | Expert needs increase operational and execution costs. |
| L25 | B9-B14 | Paucity of competent workers influences supplier selection. |
| L26 | B10-B14 | Hesitation to adapt restricts vendor interaction. |
| L27 | B4-B14 | Cybersecurity risks hinder IT service providers involvement. |
| L28 | B12-B18 | Improper standards and policies create confusion about technology implementation choices. |
| L29 | B10-B18 | Reluctance to change affects awareness initiatives. |
| L21a | B8-B18 | Unstructured training affects technological awareness. |
| L22b | B9-B11 | Skill gap and the absence of research collaborators hinder innovation. |
| L23c | B10-B11 | Change aversion impedes research collaboration. |