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Leveraging Innovative Logistics for Strengthening Supply Chain Resilience in the Face of Disruptions

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Abstract: Various disturbances can affect Supply chain (SC) networks in the dynamic global environment which comprises natural disasters and geopolitical unrest and worldwide pandemics. These disturbances caused numerous organizations to endure severe delays and stockouts together with substantial financial losses which uncovered the weaknesses of typical SC models. Research explores essential steps for upgrading SC resilience while developing new strategic logistics approaches. The research examines how innovative logistical solutions help reinforce supply chains against disruption events. Fifteen managers together with senior managers alongside senior employees from Indian smart manufacturing organizations received a survey for their participation. The survey-based approach and grey relational analysis (GRA) method established complete structural relationships between the developed logistics solutions which were subjected to ranking analysis. Research involved wide literature assessments along with knowledge from operational practices which revealed the development of key logistical strategies including AI-based predictive maintenance together with Digital twins and IoT systems for flexible transportation methods. It is alongside distributed smart warehousing and workforce flexibility for skills development through blockchain security solutions alongside digital platforms for business collaborations and reverse logistics models and agile supply chain networks designed for supplier flexibility. The study classifies Digital Platforms and Cloud-Based Collaboration (LS6) and Digital Twins and IoT (LS2) through their corresponding positions in the logistics solution list. The tested innovative logistic approaches provide manufacturers with better crisis response abilities alongside operational performance improvements. Through this study researchers and practitioners gain an opportunity to initiate proactive logistics innovation strategies during disruption times by developing operational guidelines. The purpose of this study lies in its discovery of alternative logistic solutions for manufacturing organizations to deal with SC resilience challenges and their subsequent ranking by GRA methodology.

Keywords: Disruption, Supply Chain Resilience, Logistics Solutions, Supply Chain Performance

1. Introduction

The concept of logistics operates as a core managerial operation for businesses of both manufacturing and service orientation (Gupta *et al.*, 2022; Ballou, 1997). Logistics handles the planning and execution of economical raw material and inventory transportation alongside storage together with their associated data to fulfil customer needs starting from their source to their place of usage. The efficient transfer of goods depends on logistics as an essential element for the successful operation of the SC. The emergence of logistics problems in supply chain management (SCM) occurs because logistics remains a fundamental element of supply chain operations. Economic success in SC operations depends on implementing efficient and effective logistical operations (Song *et al.*, 2020). The basic definition of logistic operations extends beyond being a mere internal function for the supply chain since it delivers essential support especially in building supply chain resilience. Nonessential operational integrity maintenance alongside unexpected event management demonstrates how resilient a system truly is (Song et al., 2020). Competitive success in unpredictable situations depends on both resilience and innovation attributes (Golgeci and Ponomarov, 2013). Recent global manufacturing trends have improved the complexity of supply chains while confirming that strategic corporate logistics operations are vital elements (Stock *et al*. 2000). Globalization enables businesses to enhance their market reach which includes international business ventures alongside customer support departments. This strategy includes multiple opportunities but involves various types of risk. International business environments present significant risks that increase the likelihood of natural disasters as well as difficult the networks connecting global supply chain components (Kazancoglu *et al.,* 2024; Aydin *et al.* 2014). The SCs experience multiple types of barriers that affect political landscapes as well as geographical networks and cybersecurity frameworks and environmental sustainability needs and cultural and ethical framework standards. SC interruptions result from human errors and changes attributed to climate alterations (Katsaliaki *et al.,* 2022). The combination of climate change with distribution and procurement globalization has made supply networks more complex and breakable while simultaneously producing additional interruptions (Hendricks and Singhal 2005). Annual supply chain disruptions throughout the globe affect 56% of all businesses, which has led organizations to take these disruptions more seriously (BCI-Business Continuity Institute 2019; Katsaliaki et al., 2022).

Ambulkar *et al*. (2015), Kim *et al*. (2015) and Hussain *et al*. (2023) together with Hamidu *et al.* (2023) along with Aldrighetti *et al*. (2021) and Yu *et al.* (2019) and Polyviou *et al.* (2020) have authored leading works about SC disruption and resilience. Very few studies examine the influence of logistics operations on supply chain resilience and maintenance of functional supply chain operations throughout disruptions (Butlet, 2018). The performance of logistics systems increases through both technical and operational optimizations of related procedures (Zimon *et al*., 2020; Brah and Ying Lim, 2006; Cherchata *et al.,* 2022) and therefore advances SC resilience when focused on better logistic performance. The present work proves through evidence that unique logistical solutions function specifically to advance SC performance along with resilience. This research investigates three important questions to address the gaps in previous analysis on creative logistic solutions and SC resilience and performance concepts.

- RQ1. How to identify innovative logistic solutions for resilience?
- RQ2. What are the innovative logistics solutions that relate and strengthen to SC resilience in the face of disruptions?

To answer the aforementioned study questions, there are three objectives set, including the following research objectives. (i) Analyze how SC resilience and innovative logistics solutions are related. (ii) Building a research model around the concept. (iii) To test the theory in order to understand the connections.

Based on the literature assessment, this study identified a few innovative logistical solutions, both technological and non-technical, that can help SC resilience in order to satisfy these issues and goals. To answer these research issues, we conduct survey research with manufacturing firms. The partial least square (PLS) approach was used to evaluate the data that was gathered from the senior executive survey, which was conducted both offline and online. This article makes three contributions. First, by expanding on the existing understanding of logistic systems, this essay adds to the literature on logistic operations. Additionally, it offers factual backing for creative logistical approaches that increase SC resilience to shocks.

The following sections comprise the remainder of this investigation. Section 2 presents the pertinent literature on creative logistics solutions, and SC resilience. The research approach used to conduct the analysis is demonstrated in Section 3. The data analysis and findings of the study are presented in Section 4. Conclusions with limitations and the extent of future opportunities were presented in Section 6 after the discussion, findings, and contributions to the study were described in Section 5.

2. Literature Review

2.1 Supply Chain Resilience

The concept of SC resilience is not new; it has existed for at least 20 years and can be traced back to systems theory and risk management. Previous studies focused on risk identification and mitigation measures (Christopher and Peck, 2004). SC resilience refers to a system's capacity to respond to adversity and adapt to changing circumstances while retaining its fundamental structure and functionality (Song *et al.*, 2022; Modgil *et al.*, 2022). This idea of silence is quite broad, but it drastically shifts when the business considers global supply networks. Resilience is a system's ability to predict, prepare for, react to, and recover from interruptions while retaining its basic operations (Patel, 2023). Several multi-level approaches to enhancing SCR have been the subject of numerous studies (Holling, 1973; Sheffi, 2007; Wieland & Wallenburg, 2013). Moreover, Sheffi (2007) presented a thorough framework that highlighted cooperation, redundancy, and flexibility as essential elements of resilience. When we discuss resilience, risk management always comes up. Because of the risk, the company consistently prioritizes a robust SC free from interruptions. Accordingly, to create a robust SC, companies must recognize and evaluate the risk nodes, taking into account their seriousness, probability, and possible means of detection. At first, it was about risk management, but as time has gone on, this idea has evolved into dynamic capabilities. To gain a deeper understanding of how SCs change and respond to shocks, Ponomarov and Holcomb (2009) state that the most recent theoretical advancements have combined flexible capabilities and perspectives on complex adaptive systems.

2.2. Disruptions in Supply Chains

The term "disruption" in the context of the SC describes any hiccup or impediment in the flow of resources and products from procurement to end users (Bode *et al.*, 2017). In other words, SC disruption is defined as anything that occurs in the downstream, inbound logistics network, or upstream SC that obstructs the focus firm's normal business operations (Messina *et al.*, 2020; Sawik, 2014). Globalization, geopolitical conflicts, environmental threats, and technology improvements are all contributing factors to the disruption, which increases the susceptibility of supply networks to interruptions. Natural disasters, supplier failures and capacity constraints, technological disruptions and cybersecurity threats, and geopolitical and economic disruptions are the several categories into which disruptions can be divided (shown in Figure 1). Disruptions can be classified as global (affecting all suppliers), local (affecting suppliers in a region, such as a labor strike caused by a state's new worker regulations), or individual (affecting only one supplier, such as equipment failure, fire, etc.) (Katsaliaki *et al.*, 2020). Numerous studies have taken into account the various facets of SC and logistical disruption (Messina *et al.*, 2020; Ambulkar *et al.*, 2015). While these types of disruptions affect logistics operations, businesses can also provide various logistical solutions that improve SC resilience. For example, pandemics, cyberattacks, and natural catastrophes can all have an impact on logistics (Haren & Simchi-Levi, 2020; Wagner & Bode, 2008). On the other hand, if the company's logistics are decentralized and use new technologies, they can address a number of problems. Poor business performance, financial crises, and widespread labor stoppages in the transport sector are some of the most well-known outcomes of interruptions; nevertheless, the negative effects of interruptions differ according to the type of risk.

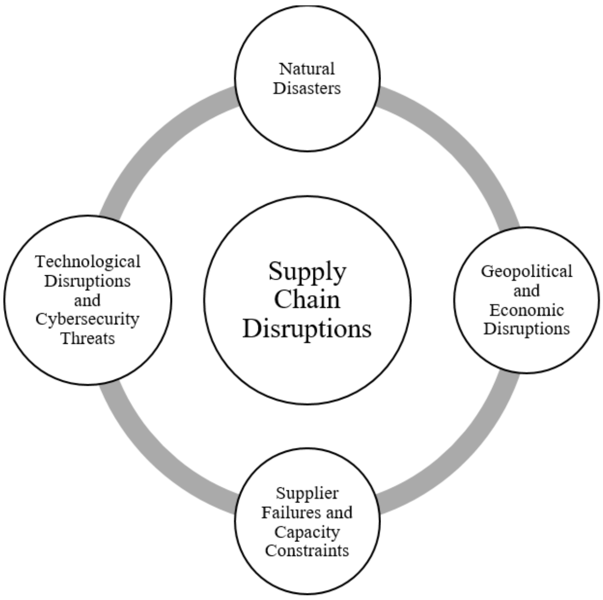

Figure 1. Supply Chain Disruptions Classification

Source: Developed by Author

2.3 Innovative Logistics Solutions

Advanced technological solutions play a vital role in making permanent standby units more reliable. Digital technologies such as blockchain and Internet of Things (IoT) technologies and artificial intelligence (AI) use predictive analytics to enhance supply network traceability and visibility in combination with blockchain (Ivanov, 2020; Bjorklund & Forslund, 2018). Supply operations and distribution methods have transformed due to advanced logistics solutions combining digital systems with automation alongside environmental-friendly processes together with IoT tracking and analytic AI algorithms and autonomous vehicles and blockchain technology according to Ivanov *et al.*(2020). Until today SC and logistics innovation shows significant growth both in practical usage and worldwide research objectives. The vital subset of SC innovation which is logistics innovation impacts total business models and encourages additional SC innovation (Ivan Su *et al.*, 2021). The introduction of innovative logistics methods leads to the establishment of sustainable SCs capable of functioning smoothly in unpredictable situations. The implementation of innovative logistics methods improves system flexibility and real-time response along with agility which results in better SC resilience. Various research confirms that locations scattered production sites and distribution networks alongside multiple suppliers together with alternative transport pathways minimize localized operational interruptions (Karanam *et al.,* 2024). According to our literature review of SC resilience we identified several innovative logistics solutions which include:

2.3.1 AI-Driven Predictive Maintenance

The logistics world has undergone a transformation with AI-driven predictive maintenance that employs AI technologies to predict asset failures in handling equipment and warehouse machinery and transportation fleets effectively. Companies used to focus on predictive analytics until the creation of predictive maintenance as an AI-driven strategy for asset maintenance (Verma, 2024). Over a series of mathematical computations and algorithmic processes data analysis discovers explanatory patterns for forecasting outcomes (Schniederjans *et al.,* 2020). Predictive and prescriptive analytics help businesses develop strategic decisions by furnishing them with sound information regarding their enterprise orientation (Wang *et al.*, 2016). The system of predictive maintenance accomplishes equipment condition maintenance through similar data analytical approaches as analytics itself.

Organizations require predictive analytics specifically to anticipate and address possible supply chain disruptions including product shortages. AI streamlines operations by managing large datasets and solving problems efficiently when predictive analytics integrates with AI systems according to Modgil *et al*. (2021) and Huang and Rust (2020). Other business developments along with globalization have made it necessary for firms to respond swiftly to customer issues. The fast-evolving modern business world benefits immensely from predictive analytics enhanced through AI technology for demand forecasting (Demirkan and Delen, 2013). Through predictive maintenance organizations operate more effectively with their assets while significantly cutting down their maintenance-related expenses. Machines equipped with AI-based predictive maintenance actively detect upcoming operational disruptions before they become issues that affect effectiveness. Study works from before have investigated how predictive maintenance is applied to industrial systems such as oil and gas and vehicle sensor systems as documented by Jambol *et al.* (2024), Omsri Aeddula *et al.* (2024) and Unlu and Soylemez (2024). Through AI-based predictive maintenance in logistics operations organizations can maintain operational flexibility alongside stronger resilience.

2.3.2 Digital Twins and IoT

DTs at their current stage of development within SCM (Zaidi *et al.*, 2024) constitute essential technological mechanisms which precisely track and duplicate their physical counterparts while enabling widespread industrial and research use. Digital twins serve multiple purposes across supply chain management together with manufacturing systems (Cai *et al.*, 2017; Wang *et al.,* 2020). The data table of Digital Twins includes operational records and sensor measurement data together with object representations. The development process of Facility System and Application scenarios using digital twins can be accomplished within brief timeframes. Digital twins strictly depend on the IoT as this framework serves both as the foundation for data sharing and represents the main technology required to generate these digital entities (Lv *et al.*, 2022). A platform based on The IoT enables the connection of sensors along with actuators and objects through smart technologies. IoT facilitates the creation of innovative, highly productive, and efficient services and offers rapid access to data about physical objects (Bandyopadhyay & Sen, 2011; Bi et al., 2014). Ivanov and Dolgui (2021) explain that the digital twin technology serves two main functions: supply network mapping and improved network visibility. The technology supports flaw mining in secrecy and enables fast scenario creation which allows planning teams to discover solutions for quick response. The disruption of a SC network due to economic, natural, technological, political or geopolitical factors becomes manageable through digital twin applications that measure the situation proactively to maintain smooth organizational operation (Abideen *et al.,* 2021). The DT platform enhances SCM operational performance according to Zaidi *et al.* (2024) and Marmolejo-Saucedo (2020). Logistics systems make use of digital twins to simulate their supply chain procedures as well as transportation networks and warehouse operations. Logistics companies will achieve better operational visualization and modeling together with optimization through creating digital replicas of their tangible resources.

2.3.3 Blockchain for Security and Transparency

Blockchain operates across industries and industrial sectors and supports logistics management along with other sectors (Akram and Bross, 2018; Ahmad *et al.,* 2021). Numerous researchers or studies begin their exploration by focusing on black chain technological improvements (Raja *et al.*, 2022; Xu *et al.*, 2021; Koh *et al.,* 2020; Hackius and Petersen, 2017). Through blockchain the product digital trail becomes observable and traceable because transaction records are fully auditable and time-stamped blocks can be built for every event following the digital trail (Wang et al., 2019). A decentralized ledger system protected by blockchain technology tracks supplies and transactions end-to-end throughout the SC network for real-time monitoring of all participants (Cole *et al.*, 2019). Scientific research classifies distributed ledger blockchain technology as a leading application for supply chain management (Lamming *et al.,* 2001). The adoption of blockchain technologies increases industry trust between partners because it facilitates quick detection of fraud as well as inconsistencies (Akram and Bross, 2018; Morgan *et al.,* 2018). Transparency entails information exchange between various SC network actors (Cho *et al.,* 2017). Blockchain enhances reaction abilities to disturbances through its features of traceability and enhanced accountability (Cheng and Simmons, 1994). Every commodity exchange is documented by blockchain systems so businesses can track their supply chains. By tracking supply chain movements through blockchain technology companies can easily adjust operations when facing unexpected disturbances and continue supplying their customers (Sunny *et al.*, 2020). The study by Issaoui *et al.* (2019) identified blockchain technology applications in smart logistics through four domains including information systems and transportation systems as well as financial processes and management processes.

2.3.4 Flexible and Collaborative Transportation

The physical connection of supply chain operations between suppliers and customers depends on transportation because it enables resource and material movement (Naim *et al.,* 2006). The performance of the SC grows better when transportation facilities show sufficient adaptability and work together effectively. The current global competitive environment demands firms to become collaborative in order to succeed for effective operation (Verdonck *et al.,* 2013). Flexible and collaborative transportation establishes itself as an evolving logistics system which builds joint operational efficiency along with flexible relationships between vendors who participate in supply chain management operations. The method integrates pooled transportation assets into a system where dynamic routing occurs through partnerships between shippers and carriers and logistics providers for maximizing operational efficiency. The fundamental dimensions of cooperative transportation management are established by trading partners who join forces with carriers participating in the supply chain system based on Chan and Zhang (2011). The implementation of this method reduces SCM inefficiencies as it allows improved physical distribution operations flexibility. Flexible transportation methods that involve cooperation between supply chain partners create essential logistical flexibility that advances operational efficiency and customer service success (Barad and Even Sapir, 2003; Zhang *et al.,* 2005). The SC resilience gains advantage through flexibility capabilities that allow companies to reroute their shipments while adjusting delivery schedules when unforeseeable events occur (Ivanov 2020). The utilization of shared transportation resources leads to better usage of equipment and reduced environmental pollutants and enhanced service delivery frequency (Cruijssen *et al.,* 2007). The resource sharing function within collaborative transportation allows businesses to manage their operational capacity boundaries alongside service delays (Carbone *et al.,* 2017).

2.3.5 Workforce Flexibility and Skills development

Laborers who performed well-established tasks obtained management influence which was a common characteristic typical of skilled workers (Mendes & Machado, 2015). Staff members develop efficient responses to changing opportunities and difficulties through education programs. Workers comprise an essential company resource which enables them to contribute knowledge to boost productivity and competitiveness (Ozen and Kazancoglu, 2022). Workforce flexibility describes the process of relocating employees among different workplace functions or locations to meet changing operational needs. A substantial benefit of organizational adaptability is the ability for companies to swiftly react when SC interruptions happen and when labor shortages and demand surges take place (Deloitte, 2020). Businesses demand more workers who master digital technology because these skills will modernize supply chain operations (Foroughi 2021 / Berry and Mok 2018). The implementation of digital technologies that affect logistics together with SC operations demands essential upskilling and reskilling of employees. Organizations that fund employee training initiatives create preparedness for dealing with both modern technological advances and shifting supply chain functions (Sarkis *et al.*, 2020). The new learning environment enables people to develop existing abilities while mastering new ones. The importance of staff expertise for the supply chain demands companies to value employee digital competence above experience and tenure per Poiteven *et al*. (2017). Makarius and Srinivasan (2017) established in their skills and talent management study that SCM creates a skills misalignment. The researchers worked to solve this gap because it hampered business-talent provider cooperation.

2.3.6 Warehousing (Smart and Distributed)

Narrowing down to actual storage operations and order fulfillment tasks such as receiving and allocating objects and order picking and loading goods become known as warehousing (Ding et al., 2021). Logistics management relies heavily on this particular aspect. The implementation of smart and decentralized warehouses helps enhance supply chain resilience in cases of interruptions such as production shutdowns and transportation delays along with inventory deficits (Patari *et al.,* 2022; Kamalahmadi and Parast, 2016).

The smart warehouse constitutes a cyber-physical infrastructure which permits independent decision-making through IoT-generated real-time data and seamless connection between mechanical and computational components (Min, 2023; Sahara and Aamer, 2022). The system leverage robotics alongside AI technology as well as IoT capabilities for real-time monitoring functions that enhance the speed alongside decreasing costs and improving accuracy (Boysen *et al.,* 2019). Modern supply networks depend mostly on effective inventory management and warehousing which makes warehouses the primary location of robots operating in logistics (Baker, 2007). The primary mission of warehouse management intends to minimize financial hazards by producing swift responses and maximizing manufacturing speeds for perfect inventory accuracy (Ali *et al.,* 2024).

2.3.7 Digital platforms and cloud-based Collaboration

Organizations recognize that supply chain disruptions affect stakeholders at diverse points throughout the network (Ivanov *et al*., 2022) therefore they are now developing collaborative partnerships to enhance their resilience plans. Organizations recognize collaborative solutions as essential components when they aim to strengthen their supply chain resilience. The technologies present throughout the SC offer point-of-need communication functions as well as data exchange and decision frameworks that enable organizations to take rapid action during interruptions. The analytical technique of prediction helps businesses identify upcoming demand alterations before they escalate (Ivanov & Dolgui, 2021). Cloud-based technology enables organizations to track their supply chain in real-time for accurate shipment observability and inventory maintenance and supplier quality assessment. Real-time visibility functions as an essential element for SC resilience according to Snyder *et al*. (2021). Cloud-based platforms provide organizations with features that include resource pooling as well as rapid flexibility combined with measurable service and extensive network access with on-demand self-service (Giannakis *et al.*, 2019). Cloud-based collaboration systems allowed businesses to reestablish their supply chains and locate new suppliers and share resources throughout the COVID-19 pandemic emergencies (Choi *et al.,* 2020).

2.3.8 Circular SC and reverse logistic

Businesses deploy sustainable and resilient SCM approaches to reduce effects on disruptions together with environmental concerns (Chaouni Benabdellah *et al.,* 2021). Every participant within SC systems needs to adopt principles from circular economy approaches to handle disruption events. The circular economy maintains a close relationship with reverse logistics because experts consider reverse logistics equally important to circular economy principles (Ding *et al.*, 2023). In SCM setting these two concepts support each other through their connectedness. Two separate perspectives exist regarding circular SC definition with waste reduction and resource preservation as one standpoint and value recovery and economic benefits as the other (Jain *et al.,* 2018). The use of circular models allows SCs to speed up their recovery from disruptions by operating with existing components rather than new supplier deliveries especially during times of supply limitations (Genovese *et al.*, 2017). The circular economy defines remanufacturing capability as an organizational strength that improves SC network stability and reliability by relocating both inside and outside resources to boost operational transparency (Sugimura and Murakami, 2021; Ambrosini and Bowman, 2009; Bag *et al.,* 2019). The implementation of these approaches provides essential flexibility (Bag *et a*l., 2019) and operational stability by reducing business reliance on fresh resources (Mishra *et al.,* 2023) and promoting waste management (Wilson, *et al.*, 2022) and alternative material sourcing hence reducing production interruptions.

2.3.9 Agile Procurement and Supplier Diversification

Literature shows significant interest in the procurement issue among many SC problems such as supply uncertainty, technology barriers, transparency, visibility, distribution, last-mile delivery, etc. (Liu et al., 2010). The changing market demands require businesses to implement agile procurement as their game-changing solution for maintaining competitiveness (Cooper, 2024). The literature demonstrates that agile procurement improves operational resilience while trimming delivery durations as a vital response to unforeseen situations (Christopher and Towill, 2000; Gligor *et al.,* 2012). The risk management strategy of supplier diversification operates as a direct counterpart approach to agile procurement since it reduces the impact of disruptions through avoiding supply chain reliance on a few providers. The implementation of supplier diversity by companies enables protection against risks that stem from political unrest and environmental disasters as well as regional and supplier-system disruptions (Tang, 2006). Enterprise competitiveness together with business performance benefits from operative effectiveness through SC distributions that reach global markets (Liu, *et al.*, 2010).

3. Research Methodology

3.1 The Case Study

With a long history spanning more than 80 years, Case Industry is one of India's top furniture brands. The case industry was founded in 1945 and is a division of the huge Group, an Indian conglomerate renowned for its wide range of activities. The case industry sells a variety of furniture items, such as office furniture, dining sets, sofas, beds, and closets. They are well-known around the nation and serve both residential and business clients. The case industry's dedication to sustainability is one of its distinctive selling features. Using eco-friendly products, cutting waste, and encouraging energy-efficient techniques throughout their production and distribution operations are just a few of the measures they have put into place. In order to improve the client experience, the care sector has also adopted technology. Customers can browse and buy their products on their dedicated website and mobile app. Customers can also touch and feel the products in their nationwide network of real showrooms before making a purchase.

After the replies were gathered, we determined that there were fifteen decision-makers (DMs) among the respondents. Nine essential logistical solutions are found in the semi-structural interview and the present literature. Figure 2 shows a flowchart of the proposed research effort for the current study.

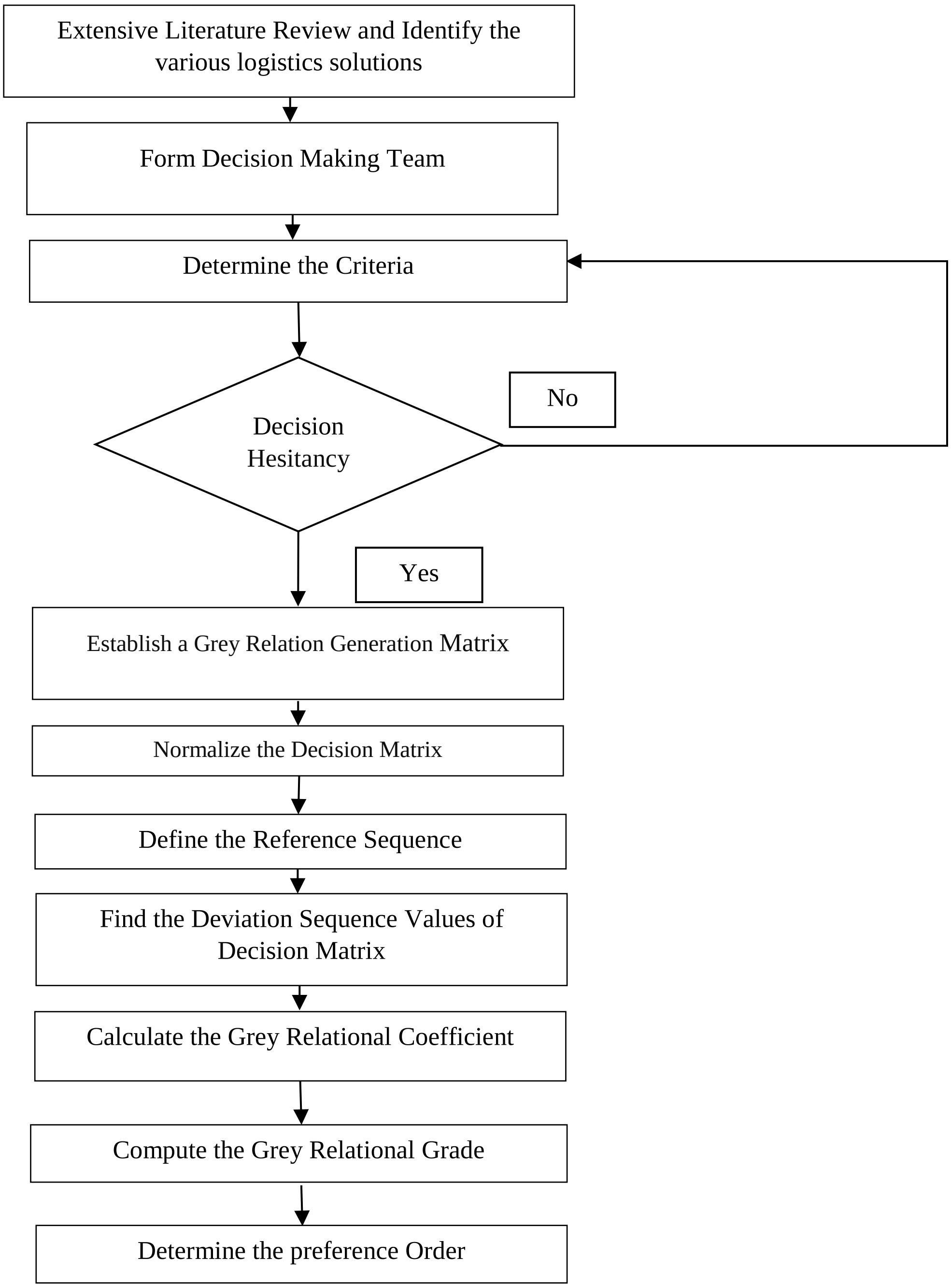

Figure 2. Flowchart of the proposed research work

3.2 GRA Method

The "grey relation" is the incomplete information relationship between these data, and "grey" in grey system theory refers to primitive data with weak, fragmentary, or ambiguous information (Liu *et al.,* 2022; Javanmardi & Liu, 2019). The GRA technique can be used to calculate gray relational grades (GRGs) (Wei, 2011; Azzeh *et al.,* 2010) and address problems involving complicated interrelationships between many components and variables (Zadeh, 1973), commonly known as many characteristics and criteria. The process of creating grey relational coefficients to address confusing systemic problems with little information is known as "grey relational generation" (Song and Shepperd, 2011; Rui and Jiatai, 2007). The GRA technique is popular, extensively used, and computed for choosing and rating performance options instead of depending on expert judgment. Most MCDM approaches consider multiple dimensions of criteria with multiple dimensions of alternatives and generate multiple dimensions of chosen criteria to one dimension of alternative in order to assess the quality of the criteria and address various selection challenges for this decision model. The effectiveness of a similar procedure called gray relational generation is being investigated. The gray relational coefficients between each comparability sequence and the reference sequence are calculated when a reference sequence also referred to as the ideal target sequence is built using this sequence as a basis. The gray relational grade (GRG) is then identified using these coefficients. If the translated comparability sequence has the highest GRG between itself and the reference sequence, the alternative is the best and the last is the worst. These steps describe the GRA technique (Liu *et al.,* 2022; Javanmardi and Liu, 2019).

Step 1: Grey relation generation (normalization)

To transform all performance values for each alternative into a consistent sequence when distinct selection criteria have different units, normalizing—also referred to as gray relational generation or data preparation is necessary. If a decision-making problem has m alternatives and n criteria, the i[th] alternative can be written as Y_i = (y_{i1}, y_{i2},....,y_{ij},...,y_{in}), where y_{ij} is the performance value of criterion j of alternative i. Using Equation (1) or Equation (2), the term Y_i may be converted into the relevant comparability sequence, X_i = (x_{i1}, x_{i2},...,x_{ij},...,x_{in}) (2). If the criterion that is a greater value is preferred and it is helpful to analyze the data, Equation 1 can be used to normalize the decision matrix. Using equation 2, the non-beneficial criteria can be standardized.

$$x_{i,j} = \frac{\left[(y_{ij}) - \min(y_{ij}, i = 1,2,..., m)\right]}{\left[\max(y_{ij}, i = 1,2,..., m) - \min(y_{ij}, i = 1,2,..., m)\right]} \quad (1)$$

$$x_{i,j} = \frac{\left[\max(y_{ij}, i = 1,2,..., m) - (y_{ij})\right]}{\left[\max(y_{ij}, i = 1,2,..., m) - \min(y_{ij}, i = 1,2,..., m)\right]} \quad (2)$$

Step 2: Define the reference sequence

Once the gray relation generation operation is completed, the performance statistics will range from 0 to 1. For a given criterion j, alternative i performs the best if the value x_{ij}, normalized using the gray relation generating approach, is equal to or close to 1 compared to the value of the other alternative. Therefore, the best choice will be made if the performance numbers of each alternative are near or equal to 1. The reference alternative is defined as $X_0 = (x_{01}, x_{02},...,x_{0j},...,x_{0n}) = (1,1,...,1,...,...,1)$ and It looks for the substitute that has the comparability sequence that is closest to the reference sequence.

Step 3: Calculate the grey relational coefficient (Ψ)

The gray relational coefficient is utilized to calculate how close x_{ij} is to x_{0j}. It is possible to calculate the grey connection coefficient using equation (3). The closer x_{ij} and x_{0i} are to one another, the higher the value of.

$$\Psi(x_{0,i}, x_{i,j}) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{i,j} + \zeta\Delta_{\max}} \quad \textit{(for i=1,2,...,m and j=1,2,...n)} \quad (3)$$

Where Ψ ($x_{0,i}, x_{i,j}$) is the grey relational coefficient between $x_{i,j}$ and $x_{0,i}$, $\Delta_{i,j} = |x_{0j} - x_{ij}|$

$\Delta_{\min}$ = min {$\Delta_{i,j}$,1,2,...,m; j=1,2,...,n}

$\Delta_{\max}$ = max {$\Delta_{i,j}$,1,2,...,m; j=1,2,...,n}

and ζ is the distinguish coefficient ($\zeta \in [0,1]$), generally taken as 0.5.

The grey relational coefficient's range is intended to be compressed or expanded by the distinguishing coefficient.

Step 4 Compute the GRG

After calculating the grey relational coefficient Ψ (x_{0i} , x_{ij}), the GRG can be calculated using the following equation:

$$\Gamma(x_0,x_i)=\sum_{j=1}^{n} w_j \Psi(x_i,x_{ij}) \quad (\text{ for } i=1,2,\ldots,m) \qquad (4)$$

Where

$$\sum_{j=1}^{n} w_j = 1$$

And the weight of the j^{th} criteria, w_j, is determined by the decision-maker. The degree of correlation between the reference and comparison sequences is represented by the GRG. The comparison sequence with the highest GRG with the reference sequence is the best option. This demonstrates that the comparative sequence of the alternative is the most similar to that of the reference sequence.

4. Results and Discussion

There are fifteen decision-makers (DMs) from top and middle management of the smart manufacturing company with their best practices with the research topics posed in this research report. Every one of these fifteen DMs (DM1 through DM15) has a positive experience. The list of nine essential logistics solutions are used by this manufacturing organization to manage the SC process based on the literature and semi-structured interviews with these identified decision-makers.

Table 1. Demographic details of the respondents

Profile	*Classification*	*Count*
Gender	Male	10
	Female	5
Age	21-30	4
	31-40	8
	41-50	3
	Above 50	0
Designation	Manager	3
	Supervisor	6
	Senior manager	4
	Executive	2
	Diploma	2
Level of Education	Bachelors	8
	Post Graduate	5
	Managerial	11
Current Job Position	Technical	4
	1-5 years	3
Current Organization Tenure	6-10 years	5
	11-15 years	4
	16 and above years	3
	1-5 years	3
Overall Work Experience	6-10 years	5
	11-15 years	4
	16 and above years	3
	Warehouse	3
	Logistics	4
Position in the organization	Audit	1
	Accounting	2
	Human Resource	2
	Business Division	3

Table 2. The scores of the decision matrix

SN	LS	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
1	LS1	5	3	4	4	4	4	4	5	5	5	4	4	4	3	4
2	LS2	3	5	3	4	4	3	3	4	3	3	3	4	4	3	4
3	LS3	4	3	5	4	3	3	4	3	3	4	4	3	5	4	4
4	LS4	4	5	5	5	4	5	4	5	5	4	4	4	5	4	5
5	LS5	5	4	5	5	4	4	5	4	4	4	4	5	5	4	5
6	LS6	3	5	5	5	5	5	3	5	4	4	5	5	5	4	5
7	LS7	4	3	3	5	4	5	3	5	4	4	3	3	4	4	5
8	LS8	5	4	4	4	4	4	5	4	4	5	5	4	5	4	5
9	LS9	4	5	4	5	4	5	5	4	4	4	5	4	4	4	5
Min		3	3	3	4	3	3	3	3	3	3	3	3	4	3	4
Max		5	5	5	5	5	5	5	5	5	5	5	5	5	4	5

Table 3. Normalized values of decision matrix

SN	LS	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
1	LS1	1	0	0.5	0	0.5	0.5	0.5	1	1	1	0.5	0.5	0	0	0
2	LS2	0	1	0	0	0.5	0	0	0.5	0	0	0	0.5	0	0	0
3	LS3	0.5	0	1	0	0	0	0.5	0	0	0.5	0.5	0	1	1	0
4	LS4	0.5	1	1	1	0.5	1	0.5	1	1	0.5	0.5	0.5	1	1	1
5	LS5	1	0.5	1	1	0.5	0.5	1	0.5	0.5	0.5	0.5	1	1	1	1
6	LS6	0	1	1	1	1	1	0	1	0.5	0.5	1	1	1	1	1
7	LS7	0.5	0	0	1	0.5	1	0	1	0.5	0.5	0	0	0	1	1
8	LS8	1	0.5	0.5	0	0.5	0.5	1	0.5	0.5	1	1	0.5	1	1	1
9	LS9	0.5	1	0.5	1	0.5	1	1	0.5	0.5	0.5	1	0.5	0	1	1
Min		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4. Deviation Sequence Values of Decision Matrix

SN	LS	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
1	LS1	0	1	0.5	1	0.5	0.5	0.5	0	0	0	0.5	0.5	1	1	1
2	LS2	1	0	1	1	0.5	1	1	0.5	1	1	1	0.5	1	1	1
3	LS3	0.5	1	0	1	1	1	0.5	1	1	0.5	0.5	1	0	0	1
4	LS4	0.5	0	0	0	0.5	0	0.5	0	0	0.5	0.5	0.5	0	0	0
5	LS5	0	0.5	0	0	0.5	0.5	0	0.5	0.5	0.5	0.5	0	0	0	0
6	LS6	1	0	0	0	0	0	1	0	0.5	0.5	0	0	0	0	0
7	LS7	0.5	1	1	0	0.5	0	1	0	0.5	0.5	1	1	1	0	0
8	LS8	0	0.5	0.5	1	0.5	0.5	0	0.5	0.5	0	0	0.5	0	0	0
9	LS9	0.5	0	0.5	0	0.5	0	0	0.5	0.5	0.5	0	0.5	1	0	0
Min		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 5. Grey relation Coefficient of decision matrix

SN	LS	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
1	LS1	1	0.333	0.5	0.333	0.5	0.5	0.5	1	1	1	0.5	0.5	0.333	0.333	0.3333
2	LS2	0.333	1	0.333	0.333	0.5	0.3333	0.33	0.5	0.333	0.333	0.33	0.5	0.333	0.333	0.3333
3	LS3	0.5	0.333	1	0.333	0.333	0.3333	0.5	0.333	0.333	0.5	0.5	0.333	1	1	0.3333
4	LS4	0.5	1	1	1	0.5	1	0.5	1	1	0.5	0.5	0.5	1	1	1
5	LS5	1	0.5	1	1	0.5	0.5	1	0.5	0.5	0.5	0.5	1	1	1	1
6	LS6	0.333	1	1	1	1	1	0.33	1	0.5	0.5	1	1	1	1	1
7	LS7	0.5	0.333	0.333	1	0.5	1	0.33	1	0.5	0.5	0.33	0.333	0.333	1	1
8	LS8	1	0.5	0.5	0.333	0.5	0.5	1	0.5	0.5	1	1	0.5	1	1	1
9	LS9	0.5	1	0.5	1	0.5	1	1	0.5	0.5	0.5	1	0.5	0.333	1	1

Table 6. The Summary of Grey Relation Grades and Ranking

SN	LS	GRG	Rank
1	LS1	0.578	7
2	LS2	0.411	9
3	LS3	0.511	8
4	LS4	0.80	2
5	LS5	0.767	3
6	LS6	0.845	1
7	LS7	0.60	6
8	LS8	0.722	4
9	LS9	0.722	5

Additionally, an MCDM technique GRA has been used to examine the important SC strategies in order to determine their priority relevance within the context of the smart manufacturing organization. Scores have been created for each of these important logistical solutions based on the experience of DMs (DM1 through DM15). The DMs' demographic data is displayed in Table 1. Table 2 displays the decision matrix scores for each of the logistics solution while normalized values of decision matrix of the GRA technique, which involves converting the scores of all the important logistical solutions into a comparability-normalized sequence are presented in Table 3. The Decision Matrix Deviation Sequence Values are presented in Table 4 and the Grey relations Decision matrix coefficient with the summary of GRGs and ranking are shown in Table 5 and Table 6 respectively.

Table 6 shows the final rank of logistics solution ranking, which is in the sequence of following logistics solution LS6>LS4>LS5>LS8>LS9>LS7>LS1>LS3>LS2. The nine smart manufacturing and service operations approaches were evaluated using the GRG approach, which produced informative rankings based on their relevance and applicability in the context of Industry 4.0. Cloud-based collaboration and digital platforms (LS6). The strategy with the highest GRG value (0.844). Digital ecosystems are essential to enabling seamless collaboration, data sharing, and operational effectiveness amongst businesses. Following GRG values of 0.766 and 0.8, respectively, were Workforce Flexibility and Skills Development (LS5) and Flexible and Collaborative Transportation (LS4). These strategies are necessary to guarantee adaptability and effectiveness while managing labor and logistical concerns in dynamic and unpredictable situations. Agile Procurement and Supplier Diversification (LS9) and Circular SC & Reverse Logistics (LS8) both scored 0.722. Proving their importance in creating strong, long-lasting supply networks. The danger of resource scarcity and supply disruptions is decreased by diversification and circularity. With a GRG of 0.6, Smart and Distributed Warehousing (LS7) is positioned in the middle. Robotic and automated warehousing solutions are crucial for reducing lead times and enhancing inventory control. With GRG values of 0.511 and 0.577, respectively, Blockchain for Security and Transparency (LS3) and AI-Driven Predictive Maintenance (LS1) received lower ratings. Even though these strategies are essential, they may now be limited by execution barriers like high upfront costs or integration challenges. LS2 was the lowest for digital twins and IoT, at 0.411. Despite their enormous potential, they can be given a lower ranking because of things like technical expertise, high processing demands, and data interoperability.

Digital Platforms and Cloud-Based Collaboration (LS6) are the most significant strategies in the context of Industry 4.0, indicating their vital importance and effectiveness. Human capital development and operational flexibility are key components of LS4 (flexible and collaborative transportation) and LS5 (workforce flexibility and skills development). LS8 (Circular SC & Reverse Logistics) and LS9 (Agile Procurement and Supplier Diversification) both have GRG values around 0.72. Their significance lies in enhancing sustainability and SC resilience. LS7 (Warehousing-Smart and Distributed) indicates its moderate relevance, most likely as a result of its partial reliance on automation and the IoT. Due to difficulties in implementation or a lack of preparedness, LS1 (AI-Driven Predictive Maintenance) is only moderately applicable. At the bottom of the list are LS3 (Blockchain for Security and Transparency) and LS2 (Digital Twins and IoT). These findings point to potential obstacles including expensive prices, specialized knowledge, or low adoption rates at the moment. Figure 3 shows the ranking of the logistics solutions.

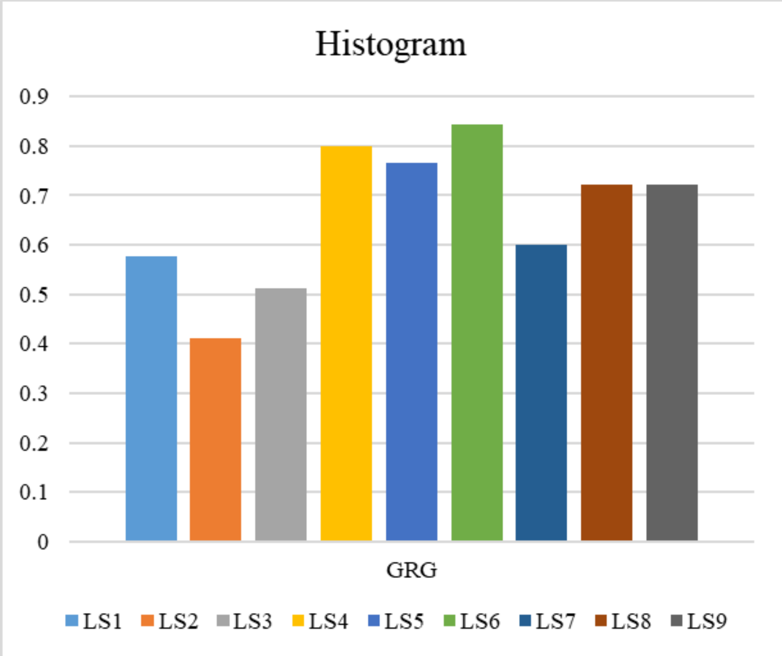

Figure 3. Ranking of the logistics solutions

4.1 Theoretical Implications

In the face of disruptions, this study identifies innovative logistics for enhancing SC resilience. In past studies on logistics and SC innovation, there is a significant lack of contemplation or theory around the "how to get there" procedures and how businesses and organizations set up procedures for innovative logistics (Su *et al.,* 2010). Moreover, Su *et al.* (2010) focused majorly on innovation problems and transportation issues. However, the current study focuses on innovative logistic solutions with the consideration of technological aspects. These solutions add value to the current literature on logistics management in the business. Moreover, the study gives the ranking of variables. Innovative logistics solutions, driven by emerging technologies like AI-Driven Predictive Maintenance, Digital Twins and IoT, Blockchain for Security and Transparency, Flexible and Collaborative Transportation, Workforce Flexibility and Skills Development, Digital platforms and cloud-based collaboration, Investing in smart warehousing, Agile Procurement and Supplier Diversification. Flexible transportation options emphasize the need for flexibility in response to environmental risks by utilizing contingency theory. Collaborative platforms to optimize resource allocation and partnership methods for mutual gain, cloud SCs integrate every SC movement (material, informational, and financial), every SC actor (suppliers, manufacturers, distributors, and customers), and every operational procedure (such as logistics, warehousing, production, procurement, sales, and returns) (Ivanov *et al.*, 2022). Although SC cooperation has several advantages, including more visibility, flexibility, and shorter lead times, it may not always be feasible (Scholten & Schilder, 2015). By combining cutting-edge technologies and sustainability concepts, creative logistics solutions are changing conventional SCM theories. A basis for creating robust, effective, and flexible SCs is provided by the interaction of theoretical models and technology capabilities.

4.2 Practical Implications

Digital platforms and cloud-based collaboration (LS6) should be given top priority by organizations in order to guarantee reliable connectivity and effective data exchange across stakeholders. This will act as a basis for the application of more cutting-edge technologies. Investing in smart warehousing (LS7) and flexible and collaborative transportation (LS P4) is crucial for increasing SC agility and operational efficiency, especially in changing market situations. Employers must make investments in upskilling staff members since Workforce Flexibility and Skills Development (LS5) is one of the best solutions. To help the workforce adjust to new procedures and technology, this includes training in AI, IoT, and advanced analytics. Additionally, hybrid workforce management solutions can boost flexibility by balancing human decision-making with technology. According to LS8, Circular SC and Reverse Logistics emphasize how crucial sustainability is becoming to business operations. Reducing waste increasing resource efficiency, and supporting global sustainability goals, organizations might implement circular practices. To reduce SC risks, agile procurement and supplier diversification (LS9) are essential, particularly when the world is disrupted by natural catastrophes, pandemics, and geopolitical unrest.

5. Conclusions, limitations, and scope of future opportunities

Important information on the nine Indian smart manufacturing and service operations techniques' applicability and usefulness in the context of Industry 4.0 is provided by the GRG methodology evaluation. The results indicate that the most important factor is Digital Platforms and Cloud-Based Collaboration (LS6), which lays the foundation for effective data exchange, collaboration, and communication among businesses. Strategies such as Flexible and Collaborative Transportation (P4) and Workforce Flexibility and Skills Development (LS5) show great importance in tackling logistical and workforce difficulties. Agile Procurement and Supplier Diversification (LS9) and Circular SC and Reverse Logistics (LS8) are two strategies that highlight the significance of sustainability and resilience in contemporary supply networks. Despite the enormous promise of strategies like Digital Twins and IoT (LS2) and Blockchain for Security and Transparency (LS3), their present lower GRG rankings draw attention to execution obstacles including high prices, the need for technical skills, and interoperability issues. All things considered, this assessment offers a strategic road map for businesses looking to successfully implement Industry 4.0 technology, with a focus on digital platforms, workforce flexibility, and sustainable practices. The Dependency of Data The quality and accessibility of the data utilized for assessment are critical components of the GRG process. Rankings may be impacted by biases in the data. Changing Context Strategies may become less relevant over time as a result of market needs, regulatory changes, or technical improvements. Specificity of Context The analysis may not adequately address regional or industry-specific issues because it is geared for broad Industry 4.0 contexts. Aspects of Quality Organizational culture and staff adoption of new technology are two examples of qualitative elements that quantitative rankings could not adequately represent.

To provide a more thorough assessment, future studies could incorporate hybrid methodologies or sophisticated multi-criteria decision-making (MCDM) tools. Frameworks for continuous assessment could be created to track how strategies' relevance changes over time. Customizing assessments for particular industries, such as logistics, healthcare, or the automotive sector, may yield more focused findings. In-depth case studies or recommendations on how to get beyond obstacles like exorbitant prices and technological difficulties might encourage wider adoption. Future research could examine how these tactics work in tandem with emerging technologies like edge AI, quantum computing, and next-generation IoT devices.

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Authors' Contributions

Priyanka Verma: Methodology, Investigation, Data collection, Data Curation, Writing original manuscript. Vimal Kumar: Conceptualization, Methodology, Investigation, Supervision, Data collection, Data Curation, Writing original manuscript. Pratima Verma: Formal Analysis, Writing, Review & Editing. Kuei-Kuei Lai: Formal Analysis, Writing, Review & Editing. Prabhkiran Kaur: Formal Analysis, Writing, Review & Editing. All the authors read approved the final version of the manuscript.

Does this article screen for similarity?

Yes

Ethics approval

No ethical clearance certificate is applicable for this present study.

Conflict of Interest

The authors have no conflicts of interest to declare. There is also no financial interest to report. The author certifies that the submission is original work and is not under review at any other publication.

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