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Digging DEEP: Futuristic building blocks of omni-channel healthcare supply chains resiliency using machine learning approach

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ABSTRACT

There is a lack of studies which have explored the factors of omni-channel healthcare supply chain resiliency (OHSCR). Thus, the current study explores the resiliency factors of healthcare supply chains (HSCs) and the development of futuristic blocks of OHSCR. In the first phase of the study, the resiliency factors of HSCs were identified through an extensive literature review and expert interviews. In the second phase, a machine learning approach, i.e., K-means clustering, was used to develop the futuristic blocks of OHSCR. Lastly, in the third phase, implications and future research propositions were discussed. The findings of this study suggest that the healthcare sector evaluating OHSCR should focus on six key building blocks: data-driven management and transformative technological adoption, flexible and transparent organisational management system, robust and diversified supply chain system, responsible and customer-centric supply chain, information sharing and knowledge management, and strategic alignment and network ecosystem. A conceptual research framework is also proposed to support future research.

1. Introduction

Global supply chains (SCs) were strained more than ever before during the COVID-19 pandemic, which caused unprecedented disruptions for most SCs and posed uncertainties and risks in demand, supply, labour, and logistics, among other areas (Ivanov & Dolgui, 2020). The outbreak of COVID-19 significantly impacted healthcare supply chains (HSCs) in terms of services, products, labour, and infrastructure directly involved in pandemic containment and provision of support for other health treatments (Tortorella et al., 2021a,b). In addition, the COVID-19 pandemic led to severe shortages of vital medical supplies, posing significant procurement issues for HSCs. Due to these disruptions, the debate to improve the resiliency of HSCs to ensure the accessibility of critical health supplies during pandemics has received increased attention (Spieske et al., 2022).

Disruption planning, mitigation, and recovery procedures for traditional HSCs were ineffective in dealing with the major COVID-19-related disruptions. As a result, many organisations altered their strategy to survive and adapt, as achieving the 'old normal' is no longer viable because the 'old equilibrium' no longer exists. The healthcare industry has transformed dramatically in recent years, with the COVID-19 pandemic serving as a trigger. Traditionally, the healthcare ecosystem has prioritised unidirectional information flow from the healthcare provider to the customer. However, in terms of consumer well-being, this paradigm fails to sufficiently engage consumers in their health decision-making (Dahl et al., 2021). Many healthcare providers have begun employing omni-channel commerce to improve the efficiency and personalisation of their products and services for their patients (Li et al., 2022). The term "omni-channel" refers to the merging of several communication channels into a single system to provide clients with

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seamless and uninterrupted service. It entails interacting with clients across numerous channels, and due to the adoption of a unified system, clients perceive their interactions with a brand or firm to be seamless. An essential characteristic of seamless integration to consumers is the capacity to switch across channels without re-entering information. A typical use-case scenario involves a user beginning to fill out a form on a website or through an app and then realising they need live support. The members must go through further authentication procedures to speak with a healthcare contact centre staff who has access to the pre-filled data (Markus et al., 2019).

Omni-channel is considered to be a complicated network with many entities and interactions between them. As a result, the integration and management of data for omni-channel ventures are essential (Mirzabeiki & Saghiri, 2020). According to the existing literature, a wide range of information and digital technologies (IDTs) have been used in the healthcare sector to handle data flows and essential connections. These include barcodes (Pisa & McCurdy, 2019), radio frequency identification (RFID) (Kumar & Rahman, 2014; Bradley et al., 2018) and electronic data interchange (EDI) (Bradley et al., 2018). However, in recent years, IDTs have advanced significantly. The application of more advanced digital transformative technologies (DTTs) such as artificial intelligence (AI), cyber-physical systems (CPS), big data analytics (BDA), and internet-of-things (IoT) in the omni-channel context has yet to be explored (Saghiri & Mirzabeiki, 2021). The use of AI may play a key role in effectively developing omni-channel HSCs, but it remains a nascent field of research (Kraus et al., 2021).

Due to the severe lack of vital medical goods caused by the COVID-19 pandemic, HSCs faced significant procurement issues. The debate over how to improve SC resilience in healthcare has gained renewed interest, as assuring the availability of such products during interruptions is crucial (Spieske et al., 2022). Through this prolonged worldwide health crisis, SC managers were compelled to rely predominantly on solutions to more temporary and foreseeable events (Ozdemir et al., 2022). In the face of catastrophes, SCs must be robust; an effective HSC must adapt, respond, and either resume its previous processes or transition to a new and preferred state (Tortorella et al., 2021). The COVID-19 pandemic created severe disruptions, reinforcing the need to generate resilience in HSCs (Senna et al., 2021).

Although there has been much debate about the resilience of SCs in the literature, limited attention has been paid to resilience strategies for HSCs. The need for research into HSC resiliency arises from the impact of disruptions extending beyond revenue and market share losses to critical issues such as patient safety. As a result, the research techniques used may differ from those used by other supply networks (Yaroson et al., 2021). Compared to other SCs in other industries, HSCs have not achieved the same level of performance or implementation of best practices. The use of omni-channels could be an ideal strategy for achieving resiliency and supply chain effectiveness (Chopra et al., 2021).

1.1. Research gaps and objectives of the study

Throughout much of the COVID-19 pandemic, hospitals around the world have been impacted by severe shortages of vital medical supplies, such as ventilators, medications, and personal protective equipment (PPE) (Spieske et al., 2022). According to Ghosh et al. (2021), due to the massive changes resulting from the COVID-19 pandemic, medical affairs have the potential to alter the course of the pharmaceutical sector. As a result, the healthcare sector must focus on omni-channel scientific engagement, consider potential external alliances, and prioritise evidence-generation projects. Also, to implement technological advances and achieve scientific excellence, medical affairs must adopt a customer-centric strategy and concentrate on cross-functional and external cooperation. With the healthcare sector shifting to new channels, the world is adjusting to these changes to relieve the massive burden on healthcare systems caused by COVID-19 (Furtner et al., 2021).

Omni-channel commerce is a relatively new trend that has substantially influenced the retail industry. Providing consumers with a consistent and seamless purchasing experience across both physical brick-and-mortar stores and digital e-commerce channels is critical for merchants (Lim and Srai, 2018). The literature suggests that integrating omni-channel into HSCs can be a more effective approach to enhance resilience (Dahl et al., 2021; Zhang et al., 2021; Sangal et al., 2022). As such, practitioners and academics are becoming more interested in omni-channel management (Thaichon et al., 2020). Examples of research fields include management and retail (Barann et al., 2020), which address issues such as shopping channel choice and shopping value. According to a recent literature analysis conducted by Gerea et al. (2021), research gaps exist in both current omni-channel frameworks and documented business cases. The process of moving from multi-channel to omni-channel has received less attention; this presents the opportunity for more empirical and theoretical study.

To address these identified gaps, this research explores factors from the literature to understand the effective integration of omni-channel approaches in HSCs to increase resiliency and further clustering factors through K-means clustering; thus, this study aims to develop futuristic building blocks of omni-channel healthcare supply chain resiliency (OHSCR). Also, future research recommendations concerning the identified futuristic building blocks of OHSCR are provided. Implementing an omni-channel approach can be beneficial for achieving higher levels of resilience and increased tolerance to disturbances. However, in the existing literature, such potential benefits have not been addressed, with only a few discussions on using an omni-channel strategy in unpredictable business contexts (Zhang et al., 2021). Managers could bridge these gaps by integrating omni-channel strategies in HSCs to improve performance and resiliency (Beaulieu & Bentahar, 2021). Considering the existing literature, researchers have demonstrated the importance and necessity of omni-channel integration; however, its facilitators and hurdles have yet to be investigated (Mirzabeiki & Saghiri, 2020). To date, a limited albeit expanding body of literature on omni-channel approach exists related to healthcare. Therefore, the current research study will explicitly address the following research questions (RQs):

RQ1: What are the main factors in achieving omni-channel healthcare supply chain resiliency (OHSCR) for developing futuristic building blocks of OHSCR?
RQ2: What are potential future research propositions based on the identified futuristic building blocks of OHSCR?

Therefore, to address the above-mentioned research questions and to fill the research gap, the main purpose of this study is to determine the main factors to help make omni-channel HSCs more resilient, develop futuristic building resiliency blocks of factors, and recommend research propositions. Thus, this study involves the following objectives:

- investigate the factors to achieve OHSCR;
- develop futuristic building blocks of OHSCR by using a machine learning approach, i.e., K-means clustering; and
- propose future propositions as per identified futuristic building blocks of OHSCR.

To meet the objectives of this study, K-means clustering is considered a suitable machine learning technique to develop futuristic building blocks of OHSCR. The K-means clustering method is a traditional clustering method regarded as an unsupervised machine learning algorithm (Sun & Yu, 2021). This method can divide the whole dataset into the best-suited group in which the data points entirely belong to a single cluster (Mohammadrezapour et al., 2020). Our findings can be used to provide practical guidance for managers and practitioners to build blocks for the integration of various HSC members using different communication channels to respond to disruptions.

The remaining sections of this paper are organised as follows: the literature review in Section 2 aids in understanding the theoretical foundation of the research and attempts to uncover factors that influence OHSCR. Section 3 discusses research methods, while Section 4 discusses the data analysis and results. Section 5 presents a discussion and the present work's distinctive contribution along with recommendations for further research. Finally, Section 6 presents conclusions and limitations.

2. Literature review

This section highlights the literature review on HSC resiliency and the role of omni-channel and explores factors for developing OHSCR.

2.1. Healthcare supply chains resiliency and role of omni-channel

HSCs have historically been linked to the logistics and procurement of healthcare services and resources. However, modern innovations in healthcare have made this perspective too limited. For instance, new capabilities have allowed healthcare management to plan for larger SC concepts, evidenced by extensive technology use, a focus on integrated care delivery, and an emphasis on aligning stakeholder interests through new reimbursement schemes. Furthermore, the complexity of interactions among healthcare stakeholders and siloed support systems provides an opportunity to investigate, analyse, and enhance this ineffective system holistically and systematically (Betcheva et al., 2021). The COVID-19 pandemic has had a significant impact on the healthcare sector and services in general, posing several constraints and challenges such as discontinuity in patient contact, unpredictability concerning service necessity and patients' timing, a shift to telemedicine and telecommunication, multiple waves of resurgence, and disruption of the entire continuum of care (Furtner et al., 2021).

Healthcare systems worldwide face enormous structural hurdles in meeting standard healthcare demands, and they have limited flexibility in responding to extraordinary events like natural disasters and epidemics. As a result, the ability to adapt to change has become a top priority. There are several internal and external challenges associated with HSCs. According to Moons et al. (2019), internal SCs in healthcare organisations are characterised by various operational challenges and complexities. Previous studies have identified internal challenges, including inventory management (Volland et al. 2017), human resource management (Khan et al. 2021), digital training and capabilities (Beaulieu & Bentahar, 2021), expiration of medicines (Nakyanzi et al. 2010), and demand information and shortage avoidance (Privett & Gonsalvez, 2014). Similarly, studies have identified external challenges, including order management (Privett & Gonsalvez, 2014), supplier relationship and customer satisfaction (Mathur et al., 2018), network management (Marques et al., 2020), supply chain administration (Beaulieu & Bentahar, 2021), and crisis management (Alemsan et al. 2022). However, with the emergence of omni-channel, involving the seamless delivery of health information and communication across multiple platforms, this may become a crucial step forward.

During the pandemic, omni-channel SCs played a critical role in helping deliver goods and services to clients' doorsteps in efforts to limit the transmission of the virus (Ivanov, 2020). While the omni-channel environment provides new and unique prospects for accelerated growth, most businesses (particularly retailers) are confronting unprecedented challenges, with the future outlook of brick-and-mortar stores in question. Retailers must keep up with rapidly changing technology and customer expectations, providing a consistent experience across all channels and blurring the boundaries between physical and digital encounters (Keskin & Harsha, 2019).

A definition of OHSCR is an integration of various healthcare organisations using different channels of communication at the national or international level for engaging with consumers, exchanging services, and information sharing (Cui et al., 2021) in response to disruptions. To ensure OHSCR, the platforms for healthcare support must incorporate medical services for both offline and online networks in which the providers schedule patients' offline appointments, perform online consultations, coordinate relevant medical records, and, through online-offline service integration, respond to online inquiries concerning follow-up and recovery at any point in time and place inside an operations management function (Huang et al., 2021). Achieving this can provide consumers with a flexible, secure, and improved experience. In addition, HSCs can deliver better value to their customers and themselves by integrating distinct online and offline channels. Also, omni-channel healthcare presents an opportunity to develop long-term relationships and brand loyalty with patients (Sangal et al., 2022).

2.2. Identification of factors to achieve OHSCR

Researchers suggest that understanding the proper integration of Omni-channel in healthcare supply chains is critical for making resilient supply networks (Tortorella et al., 2021a,b); therefore, to maximize the potential for OHSCR, these elements should be recognised and examined. As a result, in this study, it was necessary to evaluate the available literature and identify the content that addressed our purpose. The primary objective of this literature selection was to highlight the most relevant and recent studies that would be reviewed in the research. We used two databases, "Scopus" and "Web of Science" (WoS), to search the literature and explore the factors. Some of the keywords used to search within these databases were "*Health Care Supply Chain*" AND/OR "*Omni-Channel*" and AND/OR "*Resiliency/Resilient*". The titles, keywords, and abstracts of the published papers had to include these terms. The search was restricted to articles published between 2017 and 2022 to ensure that only recent research work was analysed in order to identify the factors to achieve OHSCR in the current organisational conditions. After reading the titles, keywords, and abstracts, 57 research articles were shortlisted that focused on the research topic. From the selected papers, resilience factors of OHSCR were identified. The process involved an expert in the field thoroughly reading the description of each determinant and alternative detailed in the questionnaire; these were then evaluated according to their significance in the OHSCR. Therefore, to determine the resilience factors for OHSCR, thorough literature research was conducted in the first phase. Subsequently, a brainstorming session was conducted with subject matter experts on the factors influencing OHSCR. The comprehensive literature analysis and expert validation resulted in the identification of 27 factors. After the identification of the resilience factors, a further methodological approach was applied to cluster these factors. Finally, experts were asked to validate each aspect of identification and clustering factors. The data collection process and methodological approach are presented in Section 3. The final set of factors to achieve OHSCR is listed in Table 1.

3. Research methodology

This study was conducted in three phases, as shown in Fig. 1.

In Phase 1 of the study, a brainstorming session was conducted with the research team to finalise the research topic. To identify the relevant factors of OHSCR, an extensive review was then conducted, followed by a brainstorming session with the area experts. Subsequently, the factors were finalised, as listed in Table 1. In Phase 2, a machine learning approach, i.e., K-means clustering, was employed to identify futuristic building blocks of OHSCR. In Phase 3, future research propositions were developed based on the identified futuristic building blocks of OHSCR.

3.1. K-means clustering

Clustering is a technique for identifying new categories (classes). Internal (inside the cluster) distances should be relatively small, while exterior (intra-cluster) distances should be large to be considered good clustering. The most common clustering algorithm is K-means, which

Table 1
List of factors to achieve OHSCR.

Resilience factor code	Factors to achieve OHSCR	Description	References
R1	Data-driven communication	When communicating with their corresponding populations, healthcare agencies, provinces, regions, and territories are explicit and unambiguous, and uniformity across organisations provides resilience during disruptions.	Shah and Murthi, 2021; Tortorella et al., 2021a; Snowdon, 2022
R2	Efficient inventory tracking system	An efficient inventory tracking system in an omni-channel must consolidate in real-time the available inventory at different distribution centres, shops, and supply chain locations. It must also provide a singular view of inventory data across the enterprise to determine where to fulfil an order.	Bell et al., 2018; Kembro et al., 2018; Lim and Srai, 2018
R3	Central data management and integrated database	A central and integrated database ensures that companies receive up-to-date and accurate product data that is easy to exchange, provided that companies agree to use consistent labels and data protocols.	Mirzabeiki and Saghiri, 2020; Cui et al., 2021
R4	Advanced data analytics capabilities	Advanced data analytics techniques are used to extract essential insights from huge amounts of HSC data (i.e., volume, variety, velocity, authenticity, and value), allowing for data-driven decision-making.	Cui et al., 2021; Yu et al., 2021; Savastano et al., 2019
R5	Organisational culture	Employee attitudes toward teamwork, information sharing, and risk assessment are influenced by the firm's culture. An organisational culture that is effective fosters trust and inter-firm collaboration.	Mandal, 2017; Song et al., 2019; Ishfaq et al., 2021; Song and Song, 2021
R6	Change management and training	Change management and training are the key ingredients for developing OHSCR.	Song et al. 2019; Chiu and Chuang, 2021; Song and Song, 2021
R7	Risk management capabilities	Early detection of various supply chain risks is critical for implementing countermeasures promptly to avoid supply chain interruptions. Risk management capabilities forecast possible sources of these process disruptions and analyse previous interruptions to avoid financial losses and process failures throughout the supply chain.	Song et al. 2019; Ivanov, 2021; Song and Song, 2021; Zhang et al., 2021
R8	Strategic alignment and fluent decision-making capabilities	Strategic alignment is necessary to actively integrate and align physical and digital resources. An insightful omni-channel strategy requires efficient decision-making capabilities.	Song and Song, 2021; Weber, 2021
R9	Ability to invest in new channels and processes	Human resources, physical and digital channels, mobile applications, social media platforms, modern information technology, and logistics services are all required to develop omni-channel processes. Due to the significant financial cost to establish omni-channel infrastructure, retailers plan these investments years ahead of time.	Kazancoglu and Demir 2021; Weber, 2021; Naclerio and De Giovanni, 2022
R10	Supply diversification across geographic regions	Supply diversification is important for ensuring flexible capacity to supply products amid unplanned outages. Contracts with suppliers in multiple locations are secured through supply diversification. This protects against over-dependence on a few countries or regions which increases the risk of disruption due to unforeseen occurrences like pandemics and natural disasters.	Ivanov, 2021; Saghiri and Mirzabeiki, 2021; Sharma et al., 2021; Snowdon, 2022
R11	Synchronising the operating model	Creating a synchronised operational model in which all of the company's channels are aligned and communicate with one another, as well as offering a convenient experience for customers.	Mirzabeiki and Saghiri, 2020; Huang et al., 2021; Hayes and Kelliher, 2022
R12	Robust collaboration and coordination mechanisms for	Close collaboration among partners reduces risk and uncertainty and thus	Schenk et al., 2021; Senna et al., 2021;

(*continued on next page*)

Table 1 (*continued*)

Resilience factor code	Factors to achieve OHSCR	Description	References
	government strategy, policy, and processes	supports an environment tolerant to disruptions with partners and government agencies.	Sharma et al., 2021
R13	Customer-centric supply chain strategy	In the healthcare sector, consumer trust plays a central role in developing relationships among stakeholders. The digitalisation of healthcare processes has impacted consumers' trust due to their concerns for privacy, security and information transparency. Therefore, a customer-centric supply chain strategy will play a key role in emergency response, accessing medical data, and finding a reliable service provider.	Alonso-Garcia et al., 2021; Zhang et al., 2021; Hayes and Kelliher, 2022; Sangal et al., 2022
R14	Adoption of advanced digital transformative technologies	Technology has always been a tool for process improvement. Advanced digital transformative technologies such as blockchain and IoT will help streamline and digitise essential procurement processes.	Beaulieu and Bentahar, 2021; Sharma et al., 2021; Zhang et al., 2021
R15	Trust and transparency among omni-channel partners	HSCs are characterised by disjointed structures, out-of-date processes and systems, and a lack of information sharing among stakeholders. This is due to a lack of knowledge as well as a lack of trust and transparency among trading partners. Within the supply chain, information sharing allows for better visibility.	Min et al., 2019; Cai and Lo, 2020; Mirzabeiki and Saghiri, 2020; Cui et al., 2021; Omar et al., 2021
R16	Collaborative activities among HSC members	Through increased visibility, flexibility, and efficiency, collaborative activities such as information sharing, collaborative communication, joint knowledge creation, and joint relationship efforts improve SC resilience.	Mandal, 2017; Mandal and Jha, 2018; Yu et al., 2021
R17	Network and inventory control policies	The cost of transportation in the supply chain has a substantial impact on its performance and success. Inventory control policies and networks in an omni-channel should be designed to ensure reliable and fast service, competitive transport, customer satisfaction, and sustainability in supply chain management.	Kembro et al., 2018; İzmirli et al., 2020; Naclerio and De Giovanni, 2022
R18	Boost agility with supply chain planning	Effective supply chain planning is necessary to improve risk management capabilities and boost the agility of supply chain processes to better-managed disruptions.	Ishfaq et al., 2021; Ivanov, 2021; Weber, 2021; Zhang et al., 2021
R19	Interoperability digital infrastructure	Data may be captured and exchanged between businesses, regions, and provincial and territorial health systems via interoperable digital infrastructure. Interoperability allows data to be captured and mobilised throughout information systems (for instance, finance, supply chain, healthcare, and human resources), and for data to be sent in a seamless, coordinated manner across teams, companies, regions, and countries.	Mirzabeiki and Saghiri, 2020; Saghiri and Mirzabeiki, 2021; Snowdon, 2022
R20	Robust supply chain financial system for crisis management	Supply chains require consistent financial flows; otherwise, as shown during the 2008–2009 financial crisis, many supply chains may be interrupted. During COVID-19, many leading companies endured financial difficulties and filed for bankruptcy. Therefore, a robust supply chain financial system is necessary for crisis management to adapt and respond to disruptions and return to original operations.	Kovács and Falagara Sigala, 2021; Chopra et al., 2021 ;
R21	Data capturing and sharing protocols	In an omni-channel system, data exchange among partners must be unified to reduce the cost and time required to handle data, for example, by using similar labels of goods and utilising a unique sharing system and data capturing procedure.	Hasselgren et al., 2020; Mirzabeiki and Saghiri, 2020; Tortorella et al., 2021b
R22	Solution and capabilities	Omni-channel integration in HSCs is not well understood,	Li et al., 2021; Song and Song, 2021

(*continued on next page*)

Table 1 (*continued*)

Resilience factor code	Factors to achieve OHSCR	Description	References
	assessment mechanism	and there is no effective solution that improves people's capacities. Therefore, a solution and capabilities assessment mechanism is required for management to create competitive advantages and integrate capabilities of technology and organisation for a firm's supply chain.	
R23	Responsible supply chains	Many studies have evaluated green and sustainable supply chains as sustainability has become a critical challenge. Therefore, healthcare practitioners need to manage their supply chain responsibly, leading to more socially sustainable behaviour.	Hussain et al., 2018; Fathollahi-Fard et al., 2019; Scavarda et al., 2019; Omar et al., 2022
R24	Knowledge management	Knowledge management principally seems to be neglected; however, it can promote multidisciplinary actions, leverage the flow of information, and link people, empowering employees with real-time insights and involvement.	Kumar et al., 2018; Kraus et al., 2021; Song and Song, 2021
R25	Organisation position and capabilities for merging B2B and B2C	For B2B and B2C data sharing, the current information infrastructure is insufficient. Therefore, it is necessary to understand the organisation's position and capabilities before selecting whether or not to merge B2B and B2C.	Mirzabeiki and Saghiri, 2020; (Song and Song, 2021); Zhang et al., 2021
R26	Establish and enforce effective facility access procedures	For effective omni-channel integration in HSCs, the healthcare system must establish and enforce effective facility access procedures to automatically manage facilities in online as well as online/offline channels of HSCs.	Lim and Srai, 2018; Song et al. 2019; Zhang et al., 2021
R27	Skills, abilities, commitment and experience of personnel within and across organisations	For a successful transition to the omni-channel environment, skill development is necessary. From a strategic standpoint, experienced and capable managers can reorganise the flow of work and encourage employees to collaborate more effectively. Skills and traits of managers, such as honesty and trustworthiness, can have a significant impact on the work environment and team spirit, as well as help, develop a learning-oriented culture.	Song et al. 2019; Saghiri and Mirzabeiki, 2021; Song and Song, 2021

effectively transitions from one partition to the next (Jain and Dubes, 1988; Li and Wu, 2012). K-means clustering determines whether objects are similar and clusters them (Wen and Liao, 2021). In our study, we grouped the resilience factors based on their similarity. After grouping the factors, each cluster or theme was given a name based on the similarity of the factors. The K-means clustering algorithm follows the steps described below.

If n_i is the number of samples in D_i, the mean of the sample in D_i can be written as.

$$\mu_i = \frac{1}{n_i}\sum_{x\in D_i} x$$

In the present work, an iterative optimisation algorithm for the objective function **J** was implemented.

$$\boldsymbol{J} = \sum_{i=1}^{k}\sum_{x\in D_i}\|x-\mu_i\|^2$$

K-means clustering algorithm.

Step 1. Initialise by picking k-cluster centres arbitrarily.

Step 2. Allocate each case to the centre that is closest to it.

Step 3. For each cluster, calculate the sample means.

Step 4. Reallocate all the samples to the mean that is closest to them.

If clusters are represented by their former means, the error decreased. However, if clusters are represented by their new means, the mean is always the cluster's smallest representation.

$$\frac{\partial}{\partial x}\sum_{x\in D_i}\frac{1}{2}\|x-z\|^2 = \frac{\partial}{\partial x}\sum_{x\in D_i}\frac{1}{2}\left(\|x\|^2 - 2x^t z + \|z\|^2\right) = \sum_{x\in D_i}(-x+z) = 0$$

$$\Rightarrow z = \frac{1}{n_i}\sum_{x\in D_i} x$$

If the cluster changed at Step 4, return to Step 3.

As a result, the algorithm converges after a limited number of iterations of Steps 3 and 4.

4. Data analysis and results

Referring to the research framework shown in Fig. 1, the relevant factors of OHSCR were identified through extensive review and experts' opinions. A questionnaire was then designed to assess the significant role of each factor in OHSCs using a scale of 1–5 (1 = very little significance to 5 = high significance), with the data being collected from subject matter experts. It should be noted that OHSCs are a specific topic within the larger field of supply chains; therefore, initially, it was challenging to find a group of experts with strong experience in this area. The involvement of many experts can affect the decision-making process as their views and perspectives can vary depending on their work experience, educational qualifications, and knowledge (Kumar et al., 2018). Thus, the group size can affect the efficiency of group decision-

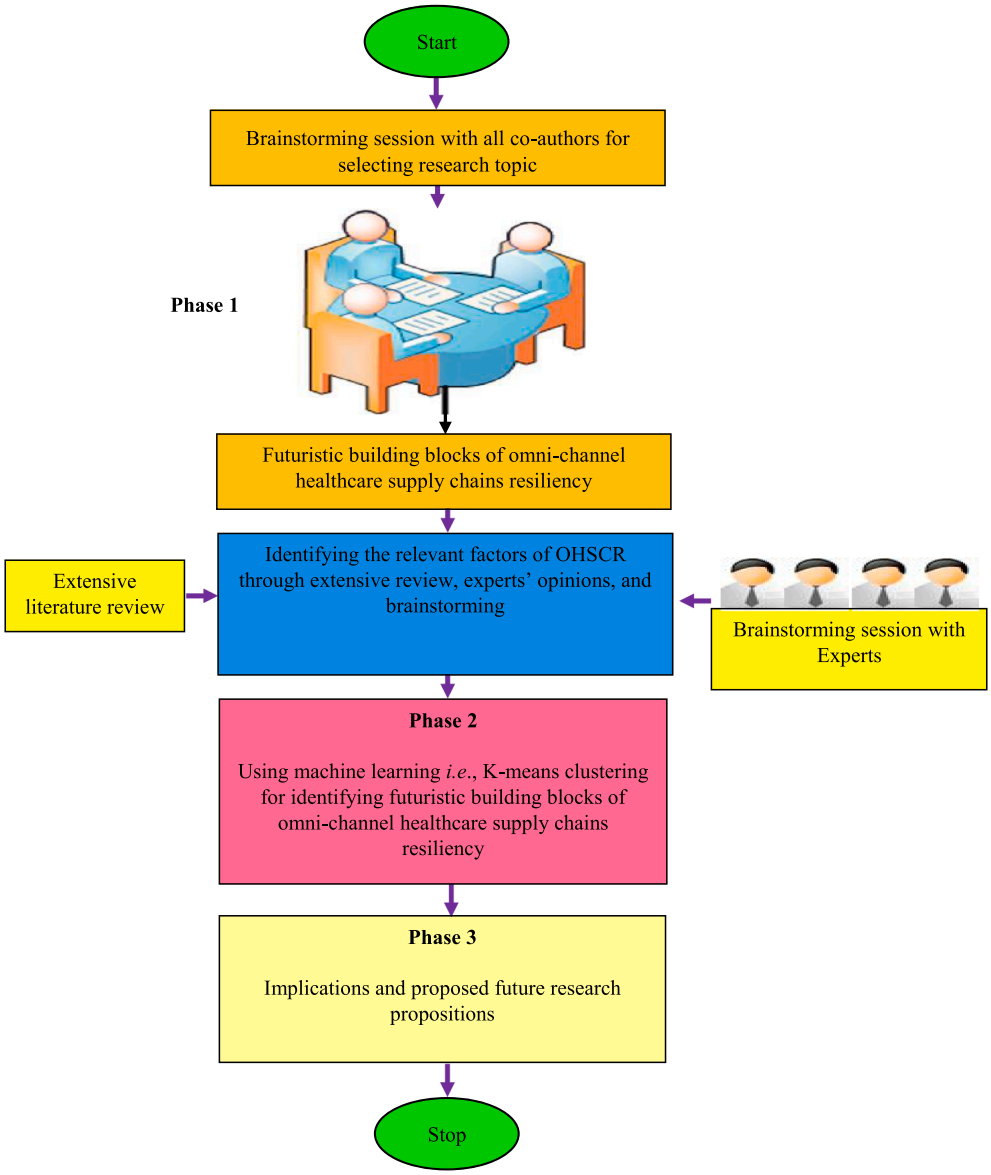

Fig. 1. Proposed research process framework.

making (Anderson et al., 2001; Chang et al., 2008; Gumus, 2009); therefore, the group size is recommended to remain in the range of 5–50 (Robbins, 1994; Gumus, 2009). To overcome the problem of group size, a snowball sampling method was used to collect data from 11 experts for this study. K-means clustering was implemented to group the factors (following the steps provided in Section 3.1). All the factors were grouped into six clusters based on the average assessments of the first six respondents and the average of the remaining five respondents, as shown in Table 2. In addition, Fig. 2 shows these clustered points with their marked centroids.

Table 2
Resiliency factors clustered by K-means clustering.

Cluster 1 (Black)	Cluster 2 (Blue)	Cluster 3 (Cyan)	Cluster 4 (Green)	Cluster 5 (Red)	Cluster 6 (Yellow)
R1	R5	R10	R13	R16	R7
R2	R6	R11	R17	R21	R8
R3	R15	R18	R23	R24	R9
R4	R25	R20			R12
R14	R27				R26
R19					
R22					

As shown in Table 2, Cluster 1 (shown in black in Fig. 2) contains seven factors and is based on the similarity among factors and is named '*data-driven management and transformative technological adoption*'. Five factors are in Cluster 2 (blue), named *'flexible and transparent organisational management system'*. Cluster 3 (cyan) contains four factors and is named *'robust and diversified supply chain system'*. Cluster 4 (green) has three factors and is named *'responsible and customer-centric supply chain'*. Cluster 5 (red) has three factors and is named '*information sharing and knowledge management*'. Cluster 6 (yellow) contains five factors and is named *'strategic alignment and network ecosystem'*. Based on the identified clusters, the futuristic building blocks of OHSCR were developed, as shown in Fig. 3. To determine the future research that could be possible under each building block, future research propositions were developed and explained within the context of existing literature in the following section.

5. Discussion and implications

This section highlights the building blocks and their respective discussion along with recommended future proposition under each

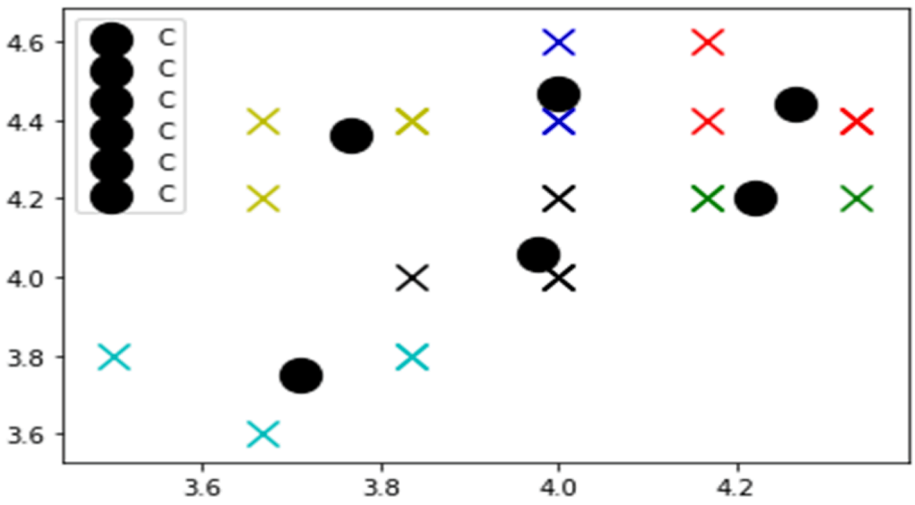

Fig. 2. Scatter plot for the average score of the first six respondents (x-axis) and an average score of the last five respondents (y-axis). Factors are grouped based on these clustered points with their centroids (marked by C) using a K-means algorithm.

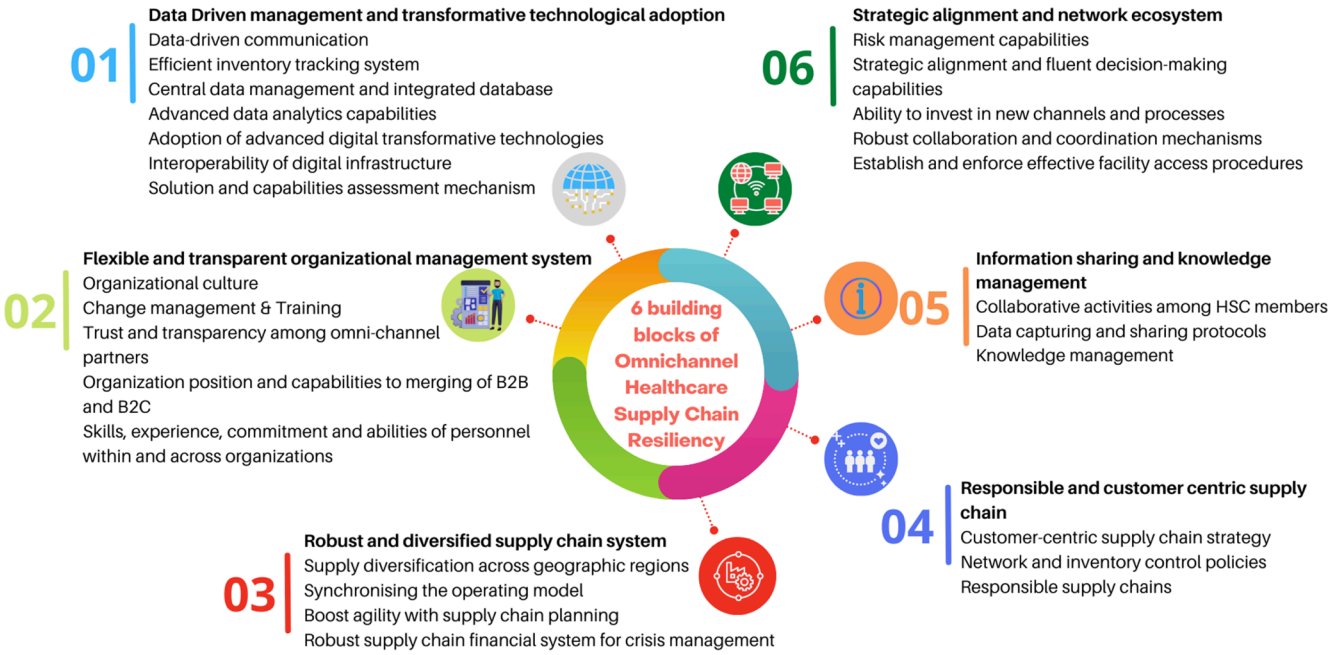

Fig. 3. Futuristic building blocks of OHSCR.

building block of OHSCR.

5.1. Building block 1: Data-driven management and transformative technological adoption

As discussed previously, omni-channel is a complicated network of many different entities and interactions (Saurin et al., 2013). As such, integration of omni-channel processes and data management is essential, and is often evaluated by synchronisation across sales, promotion, realisation, supply, and return practices (Marchet et al., 2018a, 2018b). Furthermore, demand for further research into the function of data and omni-channel data management has grown in response to a recent push toward digitalisation and online presence (Zhang et al., 2018; Bell et al., 2015).

Data integration and management are crucial mechanisms in the omni-channel context since they can enable essential resilience and compliance—far ahead of multi-channel requirements. Furthermore, by storing and exchanging data across channels in both prescriptive and predictive ways, data management can assist in dealing with variations with intra/inter-network implications before, during, and after they happen (Bradlow et al., 2017).

An examination of the retail sector provides insights into how health systems may adapt their physical and technological distribution models, allowing them to grow by adopting new technologies including flexible delivery, data analytics, blockchain, machine learning, and more. According to a report by Poulos and Morris (2022), healthcare and technology have merged to produce the best possible outcomes across the healthcare continuum. Over the last 20 years, however, technological advancements have increased pace, making it difficult for hospitals to stay up-to-date with the technological advancements. The epidemic has accelerated the deployment of virtual healthcare technologies, and institutions are being compelled to adopt technological and innovative models permanently. In this context, there is a dire need for the integration of Industry 4.0/5.0 in healthcare system processes to enable

more efficient and resilient HSCs.

Mirzabeiki and Saghiri (2020) analysed ten organisations and discovered that they employ a range of labels, technologies, and data exchange protocols across omni-channels. This information is not stored centrally; in the event of a query, such as a traceability check, authorisation is required to gain secure access. This necessitates time-consuming operations such as exchanging Excel files or emails, resulting in diminished data management competency. Furthermore, the lack of a single and integrated data system leads to data mismatches and inaccuracies which impact B2B partnerships and firms' reputations as best partners across the omni-channel. Thus, we recommend the following propositions:

Proposition 1a. *Extend data management within omni-channel to manufacturers and stakeholders to enable resiliency in the healthcare supply chain.*

Proposition 1b. *Technological adoption essentially depends on firms' dynamism and enables solution and capabilities assessment mechanisms.*

Proposition 1c. *Employ blockchain to build a unique digital identity for distinct consumers for effective patient or customer management.*

Proposition 1d. *Concerning technological adoption, Industry 5.0 applications are expected to meet the standards of an intelligent healthcare information system that can deliver higher efficiency, reliability, and effective partners/consumers management capability.*

5.2. Building block 2: Flexible and transparent organisational management system

In order to realign their SCs, retailers are digitalising their consumer interfaces and organisational procedures in response to the new challenges posed by the omni-channel age (Waller & Fawcett, 2013; Hagberg et al., 2016). Several retail SCs have begun using data and technology to increase consumer interaction and operational performance to achieve this goal (Warner & Wäger, 2019). Retailers can use the SC ecosystem to develop an organisational outlook that allows them to digitise traditional SC processes. Emerging digital SCs use corporate digital awareness to operate within an ecosystem that constantly steers the digital transformation process, according to Ishfaq et al. (2021).

Miles & Snow (2007) suggest that retail digital SCs are emerging from a different organisational structure than traditional retail SCs. Defee et al. (2009) define the traditional SC as a collection of organisational entities functioning under a defined functional framework. An advanced organisational culture, along with change management and training, is required for a resilient HSC.

Virtual technologies, such as virtual and augmented reality, are used to provide the workforce risk-free training. The goal of this transformation is to improve efficiency and production by making use of programmable machinery, gadgets, and an intelligent sensor network. Industry 5.0 performs a high-value manufacturing task to provide the required solution (Doyle-Kent & Kopacek, 2019). In healthcare organisational management, advanced technology can cater to the specific requirements of the organisation and its business partners. Hence, the following propositions are recommended:

Proposition 2a. *Extend the HSC with advanced technologies along with trust and transparency among omni-channel partners to achieve an effective management system.*

Proposition 2b. *Skills development, training, change management, and abilities of personnel are prerequisites for resilient omnichannel to merge B2B and B2C channels.*

Proposition 2c. *Integration of Industry 5.0 is required to develop resilient and efficient healthcare organizational management and operations.*

5.3. Building block 3: Robust and diversified SC system

COVID-19 has slowed the flow of information, products, and funds through SCs in many industries. In particular, lockdowns hindered the flow of resources and information, resulting in a steep decline in demand and supply shortages. In SC design, ensuring numerous channels exist for transferring information, goods, or finances is critical. During COVID-19, companies that established multiple channels to increase efficiency while dealing with regular demand-and-supply changes discovered that their organisation provided resilience at a low cost (Chopra et al., 2021). Many businesses have begun to develop omni-channel approaches that require incorporation and modification of their resources to meet new challenges; these include sustaining significant reliability of attributes, brand values, and overall image across the various services, channels offered, and continuous experiences for their consumers (Payne et al., 2017; Von Briel, 2018).

The growth of internet-based channels has recently been reflected in the marketing literature (Raza & Govindaluri, 2021), along with discussions about how incorporating e-commerce into omnichannel strategy creates synchronised advantages at the promotion and SC levels. However, several significant disadvantages prevent businesses from maximising the benefits of using e-commerce and omnichannel strategies. Even though e-commerce within the framework of omnichannel approaches can increase customer satisfaction and engagement, data management, revenue, and productivity, there is an increasing requirement to prioritise SC logistics and operations solutions capable of sustaining businesses (Autry, 2021). In practice, the omni-channel and e-commerce approach that many companies are practising significantly impacts SCM operations (Raza & Govindaluri, 2021; Marchet et al., 2018a, 2018b). To address this issue, we propose the following:

Proposition 3a. *Increase SC resiliency and robustness by incorporating e-commerce into an omni-channel strategy through the adoption of Industry 4.0 technologies.*

Proposition 3b. *Develop sustainable B2B and B2C e-commerce with the application of big data analytics and blockchain to achieve resiliency in OHSCs.*

Proposition 3c. *Improve OHSCR through modifications in SCs with a focus on technology adoption and building blocks of SC resiliency.*

5.4. Building block 4: Responsible and customer-centric supply chain

Nearly 95 % of retailers are aware of the benefits of an omni-channel approach in terms of consumer targeting, acquisition, and retention (Varadarajan et al., 2021). According to research on multi-channel purchasing behaviour, retailers value multi-channel consumers more than single-channel buyers (Kumar and Venkatesan, 2005). Consumers who buy across multiple channels are additionally more involved and active than those who only buy through one channel, bringing additional income to the company. According to Liu et al. (2018), companies must evaluate individual channels' performance to safeguard efficient resource allocation and synergies.

Through the planning of online and offline consumer actions, marketers can control consumer experience successfully through big data abilities across the buying process (Lemon & Verhoef, 2016). Venkatesan & Arunachalam (2020) show that customers' experiences can be improved via customer-centric omni-channel marketing throughout all customer touchpoints and channels. In addition, Industry 5.0 enables customers to acquire products and services tailored to their unique needs. By employing AI, this industrial revolution allows the industry to follow appropriate manufacturing processes to fulfil the concept of personalisation. This approach allows for 'design freedom,' meaning items can be more personalised while also improving production capabilities. This revolution will also aid manufacturing and automation operations.

According to research studies (Sopadjieva, Dholakia, & Benjamin, 2017), nearly 70 % of consumers buy from various channels through multiple product categories. Other reports by consulting firms in the context of Western Europe and the United States assert that nearly 95 % of retailers are aware of the benefits of an omni-channel approach in terms of consumer procurement, targeting, and retention (Varadarajan et al., 2021).

The healthcare sector is similar to the retail industry, as one of the healthcare system's core missions is to improve the patient experience. However, as the healthcare landscape evolves, healthcare organisations will need to provide a cost-effective consumer engagement strategy that is consistent across all patient touchpoints. Healthcare systems that excel at patient experience will succeed in the market and be more robust in times of crisis, following the lead of the retail industry (Poulos & Morris, 2022). In this context, Industry 5.0 and big data analytics will enable a resilient HSC based on consumer personalisation. Hence, we recommend the following propositions:

Proposition 4a. *Implement robust and resilient SC models incorporating Industry 5.0 technologies to enable healthcare SC resiliency based on consumer personalisation.*

Proposition 4b. *Interoperability in healthcare omnichannel is possible with AI to deliver proficient consumer solutions.*

Proposition 4c. *Extend healthcare SCs with an efficient inventory tracking system with Industry 5.0, machine learning, big data analytics, and technology adoption to create a diverse and flexible healthcare system focusing on consumer procurement, targeting, and retention.*

Proposition 4d. *The IoT and IoE (internet of everything) within Industry 5.0 will enhance consumer loyalty through customised experiences and provide better collaborative relationships based on data generated through blockchain, IoT, IoE, and big data analytics.*

5.5. Building block 5: Information sharing and knowledge management

Businesses and consumers now have multiple alternatives for managing information and material flow throughout demand and supply networks. These options, such as click-and-collect, home delivery, and mobile shopping, are referred to as retail channels, and the usage of various channels to sell products has become standard practice in recent years (Mirzabeiki & Saghiri, 2020; Pei & Yan, 2015). A complete network linking and coordinating processes, technology, and businesses across various channels for every product is required to achieve a dependable and steady flow of information and material across numerous channels; this network is referred to as omni-channel (Brynjolfsson et al., 2013).

The advancement of omni-channel health resource information for searching and integration are key-value co-creation components in the service delivery process (Dahl et al., 2018). Due to the absence of interoperability of multiple firms' databases, a lack of motivation for free information, and alliance exchange between them, this assimilation is challenging in omni-channel structures. The lack of information system integration and interoperability necessitates data exchange among companies, dealers, and logistics providers.

Proposition 5a. *Integrate Industry 4.0/5.0 to enable information management systems and big data to build partner or customer-centric information systems.*

Proposition 5b. *To enhance resiliency in omni-channel of HSCs, knowledge management and information sharing among healthcare supply chain members is necessary for forecasting, coordinating, and customer service.*

Proposition 5c. *Knowledge management and data capturing enable smooth information sharing among organisational members and stakeholders, and digitalised information sharing facilitate automated knowledge acquisition for SC decision-making.*

5.6. Building block 6: Strategic alignment and network ecosystem

Recent advancements in healthcare suggest that the industry could incorporate an omni-channel care delivery strategy in the future. This would involve the use of a wide range of digitally enabled healthcare delivery and communication methods. The future of AI-enabled applications as communication channels by which clients may smoothly manage their treatments from home, utilising features like remote monitoring, alerting tools, symptom-checking tools, virtual assistants, and drone delivery of healthcare goods, point to drastic changes (Varadarajan et al., 2021). Retailers may leverage their existing product, order, and customer data to improve the overall shopping experience by expanding their omni-channel capabilities through mobile in-store services (Lawry & Bhappu, 2021).

Recent studies have concentrated on identifying new omni-channel commerce difficulties and prospects (Hübner et al., 2016; Chopra, 2018). From this perspective, Bektaş et al. (2017) and Mancini et al. (2014) examined network topologies with several tiers in an urban logistics setting. They identified portfolio, fulfilment, and distribution design as fields that needed more investigation. Another study explored the barriers to multi-tier allocation system expansion concerning exorbitant prices (Savelsbergh and Van Woensel, 2016). Meanwhile, there is a large and expanding body of research on supply chain resilience (SCRES) to address multiple risks from both the demand and supply sides, such as resilience for Industry 4.0 and during and after the COVID-19 pandemic (Ivanov, 2020; Remko, 2020).

Proposition 6a. *Integrated supply chain capability, planning capability, and network-building capabilities are the foundation for a resilient HSC.*

Proposition 6b. *Industry 5.0 has the potential to add advanced functionality to offer enhanced network coordination, consumer experience, and expected benefits for healthcare systems.*

Proposition 6c. *Resilient SCs and the viability of the ecosystem of intertwined supply networks to adapt to disruptions can be achieved by implementing Industry 4.0/5.0 technologies such as digital twins, blockchain, and more.*

We have proposed a research framework based on the above discussion identifying building blocks and propositions for future research directions (as shown in Fig. 4). The framework implies that internal and external challenges associated with HSCs motivate organisations to advance their adoption of technology which will further facilitate the efficient integration of the identified building blocks. Technological adoption and these building blocks will enable HSCs to overcome internal and external challenges and further develop OHSCR. Furthermore, implementing the six identified building blocks will improve innovative performance, improve partner/customer relationships, enhance organisational systems, and deliver innovation and robustness.

6. Conclusion

This study aimed to investigate the factors to achieve OHSCR) and develop futuristic building blocks of OHSCR by using a machine learning approach, i.e., K-means clustering. The study also identifies the opportunities for Industry 4.0/5.0 integration to overcome OHSCR challenges based on the existing literature and provides propositions based on the identified factors. The resulting building blocks consisting of 27 factors were clustered into six building blocks of OHSCR: (1) Data-driven management and transformative technological adoption, (2) Flexible and transparent organisational management system, (3) Robust and diversified supply chain system, (4) Responsible and customer-centric supply chain, (5) Information sharing and knowledge management, and (6) Strategic alignment and network ecosystem.

From a theoretical standpoint, the findings constitute a first attempt to discover existing intersections by bridging the knowledge between Industry 4.0/5.0 and OHSCR. By considering the omni-channel HSC to

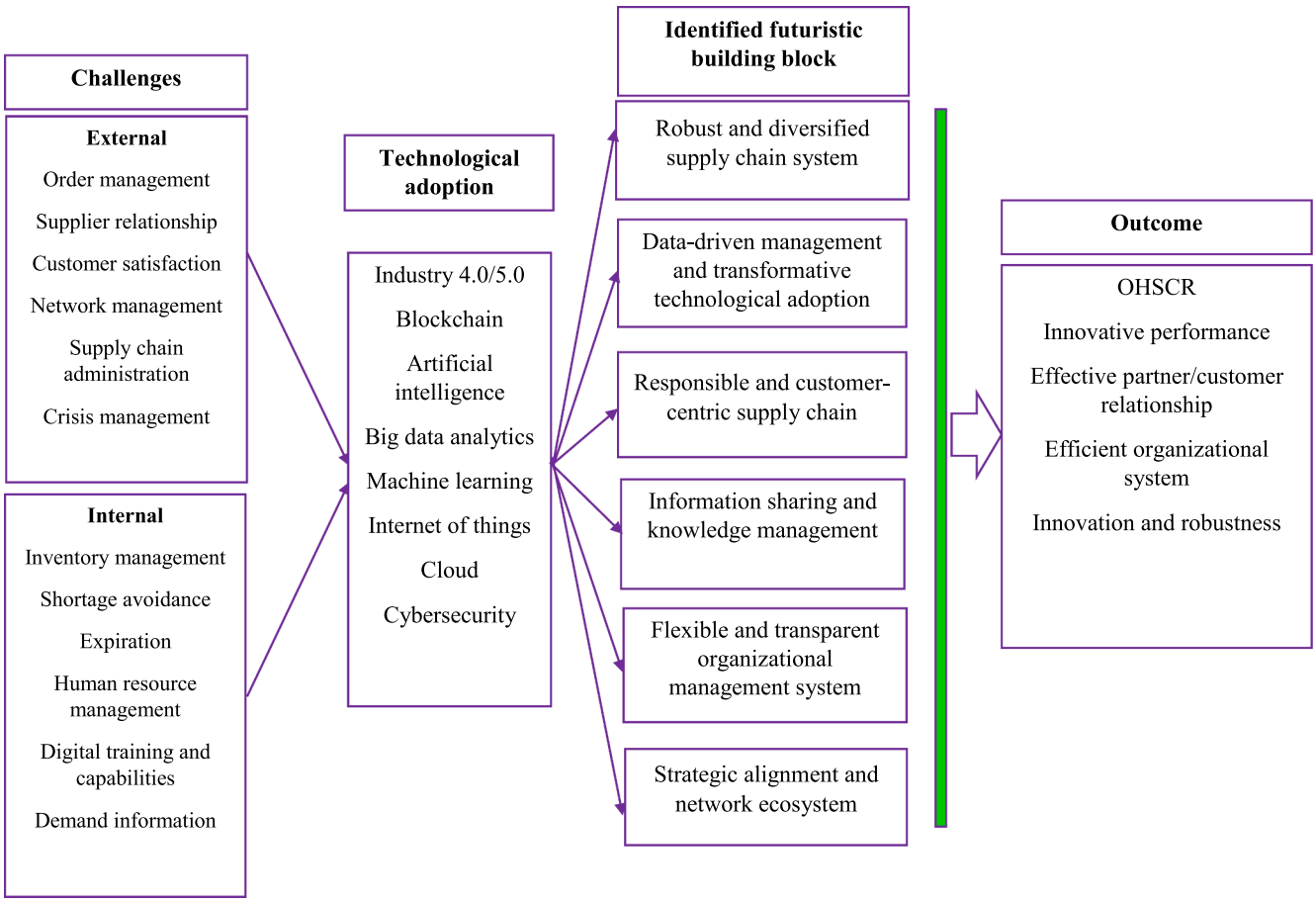

Fig. 4. Conceptual framework for future research.

be a system, identified building blocks can be used to increase resiliency and robustness against disruptions. Researchers can organise their efforts to create modular components (for example, AI-enabled patient touchpoints) that address specific OHSCR concerns or provide actual services. From a managerial standpoint, this study's findings can aid decision-making in the area of digital innovation in the context of OHSCR, emphasising that concepts such as blockchain, big data analytics, and IoT can enable efficient partner/customer-centric healthcare omni-channel to meet the needs of both B2B and B2C channels.

Furthermore, by illustrating critical OHSCR issues and prospective solutions, this study reveals significant gaps to be addressed from a scientific and management standpoint. As with most research, there are certain limitations to this study. For example, further empirical research is needed to determine whether or not they manifest in reality. Further research should be done to examine the possibilities of implementing the other principles in greater depth.

CRediT authorship contribution statement

Anil Kumar: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Farheen Naz:** Writing – original draft, Methodology, Formal analysis. **Sunil Luthra:** Writing – original draft, Methodology, Formal analysis. **Rajat Vashistha:** Writing – original draft, Formal analysis. **Vikas Kumar:** Writing – review & editing, Supervision, Conceptualization. **Jose Arturo Garza-Reyes:** Conceptualization, Editing, Investigation, Supervision. **Deepak Chhabra:** Writing – original draft, Investigation, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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