Humanitarian supply chain framework in context of pandemic: a review

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Abstract: This review paper systematically analyses the literature on the humanitarian supply chain (HSC) framework in the context of pandemics, with a focus on identifying efforts, gaps, and future research topics. The study critically reviews 150 articles published between 1992 and 2024. The methodology includes a detailed examination of themes such as sustainability, resilience, health supply chains, and technological advancements. Key findings reveal that 40% of the literature focuses on resilience, 30% on sustainability, 20% on health-related supply chains, and 10% on technological innovations. The paper highlights the novelty of systematically analysing HSCs specifically during pandemics, providing new insights into the structural challenges and opportunities for improvement. This study will aid researchers and practitioners in developing efficient, resilient, and sustainable methodologies. Future research directions include exploring advanced technological solutions, data-driven decision making, and interdisciplinary approaches to enhance HSC resilience and effectiveness.

Keywords: humanitarian supply chain framework; pandemic; methodologies; sustainability; resilience; data-driven decision making.

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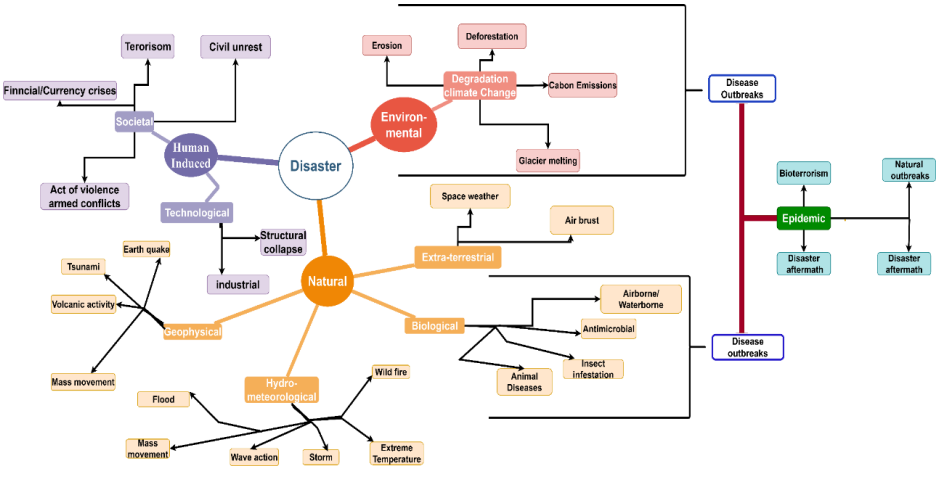
1 Introduction

1.1 Introduction

The coronavirus disease (COVID-19) outbreak has disrupted worldwide supply lines and brought to light weak areas in the chains to a degree that is unparalleled by anything that the vast majority of people have ever encountered in their lifetimes. The humanitarian supply chain (HSC) is a critical component of disaster relief and response operations, especially during times of pandemics. The COVID-19, first discovered in Wuhan in December 2019, then rapidly spread to other regions of China before becoming a worldwide pandemic in March 2020. The humanitarian sector has witnessed unprecedented challenges in managing the supply chains (SCs) with the outbreak of COVID-19. This paper provides a comprehensive review of the existing literature on the HSC framework in the context of pandemics. Several SCs have been significantly impacted by the COVID-19 epidemic. Therefore, it is important to address this significant concern. The important topics are sustainability and resilience related to SC. Also, food, SCs connected to health, and technologically assisted instruments are identified as the three main research themes by Moosavi et al. (2022). The researchers performed a thorough literature review on the interactions between pandemics, aid efforts, and vulnerable populations. They used the Scopus database to look for peer-reviewed journal papers published in English (Yagci Sokat and Altay, 2021). Nabipour and Ülkü (2021) identified areas for future research that need to be addressed as well as the shortcomings of earlier studies. Their study was centred on nine major areas that have drawn significant attention from humanitarian operations and supply chain management (HOSCM) academics. Humanitarian logistics, theory-focused research, case studies, and mathematical models were the major themes of the study by researchers (Behl and Dutta, 2019). The COVID-19 pandemic demonstrated both the fragility of SCs and the potential influence of disruptions on a large-scale global network. The literature on supply chain resilience (SCR) that joins the SC to other networks, such as transportation and command and control, and focused on resilience modelling and quantification was reviewed by Golan et al. (2020).

A few of the issues that need to be addressed include the identification of supply sources, coordination between factors, the significance of a centralised authority, the role of skilled supply chain management (SCM) professionals, the possibility of combining scarcity and abundance of resources, supply chain understanding in disaster management, and the requirement of a financial supply chain (John and Ramesh, 2012). After the Spanish flu in 1918, the COVID-19 pandemic has been regarded as the greatest global catastrophe. Lack of readiness and inefficient SCM tactics resulted in the deaths of millions of people. The usage of different sources and enhanced coordination across stakeholders are a couple of the important lessons discovered through the investigation of Kumar et al. (2022). The COVID-19 outbreak is a historic humanitarian disaster that had a profound influence on the dynamics of global commerce. As a consequence of pandemics, worldwide SCs become disorganised, which put their capacity for survival in jeopardy. Investigation of potential solutions for management of supply chain operations is required in order to address these difficulties (Farooq et al., 2021). Figure 1 show disasters threats to global supply chains.

Figure 1 Disasters threats to global supply chains (see online version for colours)



A causal loop diagram, which can help people better comprehend relationships in situations when there are plenty of unknowns, helps to depict the compounding causes that caused the cholera outbreak in Yemen. The study showed that humanitarian assistance and a country's level of infrastructure development are closely related. Constraints resulting from the crisis in Yemen have an impact on SCs, which further inhibits the usage of infrastructure and restricts access to essential products and services. In order to avoid and contain future outbreaks, it may be more effective to coordinate short-term humanitarian activities with long-term development goals (Harpring et al., 2021). The COVID-19 epidemic spread quickly and forced full or partial lockdowns around the globe. All forms of transportation suffered as a result of the global SC network being disrupted. Profitability, employment, operations, and capital spending all suffered negative effects (Bandyopadhyay and Bhatnagar, 2023). The study by Shaw et al. (2020) examined the responses from East Asian nations such as China, Japan, and South Korea and offered some insights and commonalities.

Also, the COVID-19 pandemic posed significant difficulties for the South Asian region. Any long-term lockdown scheme was not feasible given the socioeconomic conditions in the South Asian nations. However, Bhutan, the Maldives, and Sri Lanka have succeeded in stopping the disease's spread (Sarkar et al., 2020). A review of studies on ambiguous facility location issues in a humanitarian context were studied by researchers. The main objective was to assist in structuring the subject, which received more and more attention. The findings of the presentation of the state-of-the-art include the identification of current research trends and expectations, as well as gaps in the body of existing knowledge (Dönmez et al., 2021). The global pandemic that has been brought on by the newly discovered coronavirus is still a disaster and a cause for concern. As a result of the widespread devastation that the virus has wrought throughout the globe, it has become very difficult for healthcare systems in every region of the world to provide appropriate personal protective equipment (PPE) for medical personnel (Mosallanezhad et al., 2021).

Facemasks, and food products have experienced phenomenal global demand, leading to supply shortages. The study performed by Rahman et al. (2021) looked at ways to deal with the shortage of essential goods caused by a demand-supply imbalance. The COVID-19 outbreak had a substantial effect on a number of SCs around the country. The most important aspects of SC are resiliency and sustainability. Food, smart cities and their connections to health, and instruments aided by technology have been highlighted as the three primary study subjects that have emerged from research carried out by Moosavi et al. (2022). Also, labour is a vital resource in SCs which is required for transportation, storage, and distribution. When there is a pandemic, the availability of workers for various SC network operations may be disturbed by sickness, worry about spreading the disease, morbidity, the need for physical or social isolation, etc. (Nagurney, 2021). The humanitarian community has developed a collective localisation strategy. Delegating duties and resources to national and local actors is known as localisation. Because strategy execution is challenging and operation of humanitarian organisations are unclear, progress is taking longer than anticipated. The strategic decisions made by International Hydrographic Organizations (IHO) as a result of the context-sensitive advantages of localisation are one reason for the slow progress (Frennesson et al., 2022). In the context of the COVID-19 epidemic, El Baz and Ruel (2021) examined the function of supply chain risk management (SCRM) in reducing the impact of interruptions on supply chain robustness and resilience. The findings supported the central ideas of organisational information processing theories and resource-based views addressing the combining of dynamic resources to deal with disruptions' unpredictability. In the course of the COVID-19 pandemic, it became clear that a company's ability to manage risk and maintain resilience in its supply chains was an extremely valuable asset. Rapid decision-making, prompt answers, and the ability to reorganise the resource base have all been factors that have contributed to the continued existence of enterprises (Kähkönen et al., 2023).

The most important obstacles that hinder HSC's ability to operate efficiently during the outbreak are a lack of government funding and assistance, a shortage of qualified and experienced resources, and a lack of technological adoption. The research project carried out by Dohale et al. (2022) was the first of its kind to have pinpointed and examined the main obstacles to HSC operationalisation during COVID-19 in the Indian context. A study looked at how the COVID-19 pandemic has affected smart technology, green manufacturing practises, and SC crisis management plans. To test the hypothesis, data was gathered from businesses and structural equation modelling was used. The study aided SC and industrial company managers in implementing environmentally friendly methods and cutting-edge technology (Khan et al., 2022). The findings of a study conducted by the USA Naval Institute in Washington, DC, and the UK Ministry of Defence on the effects of data analytics on SCR and responsiveness during the COVID-19 pandemic have been published in the journal Cybermedicine (Munir et al., 2022).

(Michel et al., 2023) identified four main dimensions of HSC resilience, namely capacity, collaboration, flexibility, and humanitarian culture. They also provided a conceptual model of HSC resilience. Further, they concluded that subdimensions provided detailed understanding for proactive and reactive actions. Another study by Shaheen et al. (2023) explored innovation focus of food banks which differentiated resource scarcity and operating context. They observed that food banks shifted focus to process innovation during COVID-19. Silveira et al. (2023) identified relationships

between humanitarian logistics and COVID-19 pandemic. They proposed a framework that includes stages such as adaptation, digitisation, preparation, recovery, and ripple effect. Their focus was on vulnerable populations impacted by HSC failures. Patil et al. (2023) created a framework for digitisation of HSC after pandemic which included 19 drivers for the digitisation. They gave priority to operational, technological, and social drivers for HSC digitisation. Further, they offered strategies for enhancing fund collection and data management using technologies. Researchers performed a systematic review on logistics and supply chain innovation in humanitarian context. Their framework specifically addressed innovation, resource constraints, and adaptation challenges (Altay et al., 2024).

Travers (2024) conceptualised HSC resilience through lens of social capital theory and analysed 17 interviews to identify examples of leveraging social capital by local HSC networks during pandemic. He observed that communities were more resilient when they can speedily leverage social capital. Further, he provided practical policy suggestions to organisations involved in HSC networks. Khalili-Fard et al. (2024) determined optimal pre- and post-disaster decisions in humanitarian logistics for all type of organisations. They used a quantity flexibility contracts and multi-sourcing policy to improve resilience. Further, they proposed a hybrid parallel differential evolution algorithm which included reinforcement-learning based local search. (Kumar Tarei et al., 2024) studied critical challenges in the implementation of relief measures for humanitarian logistics in pre- and post-disaster. They employed combined framework of Grey-Delphi and Grey-DEMATEL based on survey results and identified existing barrier. They concluded that out-dated information technology (IT) support, unpredictable relief aids quality monitoring process, complicated geographical situations, early-warning system failure, poor stakeholders' coordination acted as barriers to functioning of humanitarian logistics. Researchers also explored relationship between logistics decisions and ethical standards for humanitarian relief operations. They used data triangulation method to collect research data from a literature review, focus group, and interviews. They concluded that physical distribution, location of facility, procurement, cost analysis, outsourcing, information flow, collaborations between supply chains, selection, training, and security of staff, relief item type affected implementation of ethical standards (Alsoussi et al., 2024). Korucuk et al. (2024) studied a real case study of selection of humanitarian warehouse. They proposed Fermatean Fuzzy LOPCOW to obtain criteria weights and Fermatean Fuzzy RAFSI to rank options. Further, they extended Delphi approach with Fermatean Fuzzy sets. Thus, their proposed model offered a robust, practical, and powerful structure for easily understandable algorithm. The necessity of integrated supply chain transparency and traceability (ISCTAT) in inter- and intra-organisational sustainability has been underscored by the COVID-19 pandemic. Also, the selection of sustainable technology footprint enablers (STFEs) is determined by the transparency requirements of adoption decisions. Therefore, Kumar (2023) assessed the relationship between ISCTAT and STF-enablers using the fuzzy-ISM approach. The architecture design of the structure matrix of STFEs was also investigated in order to determine the propulsion and reliance power of the potential of STF-enablers.

The unprecedented scale and impact of the COVID-19 pandemic on global SCs have highlighted the urgent need for a resilient and adaptive HSC framework. The present study is motivated by the challenges observed during the pandemic, including supply

shortages, disruptions in logistics, and the need for efficient coordination among stakeholders.

1.1.1 Novelty of the review

The novelty of the present review lies in its comprehensive synthesis of recent advancements in HSC management, particularly in the context of pandemics. Unlike previous reviews, this study provides a multi-dimensional analysis that integrates various critical aspects such as resilience, sustainability, technological adoption, and local-global coordination. The novel contributions include:

1 *Holistic integration of resilience and sustainability*: This study bridges the gap by exploring their interdependencies and proposing a more integrated approach while previous reviews have addressed resilience or sustainability separately.
This all-inclusive perspective is essential for building robust supply chains that can withstand and recover from disruptions.

2 *Emphasis on technological adoption*: The present review highlights the increasing importance of digitalisation and advanced technologies in HSCs. It explores utilisation of technological innovations, such as data analytics, blockchain, and AI, in enhancement of supply chain operations, which has been previously underexplored.

3 *Focus on local and global coordination*: This study emphasises the need for effective coordination between local networks and global actors. It offers a balanced perspective that recognises the unique challenges and strengths at different levels of operation, providing actionable insights for both stakeholders.

4 *Policy implications and practical strategies*: The review goes beyond theoretical analysis to offer practical policy suggestions and strategies for improving HSCs.
This focus on actionable outcomes is designed to directly influence practice and implementation, ensuring that the insights gained are readily applicable in real-world scenarios.

1.1.2 Progress against recent state-of-the-art reviews

The present study makes significant progress in several areas compared to the most recent state-of-the-art reviews:

1 *Comprehensive literature synthesis*: This review synthesises a broader range of studies to provide a more detailed and nuanced understanding of the current state of HSCs building on the works of Moosavi et al. (2022), Kumar et al. (2022), and Golan et al. (2020). It also incorporates recent findings from 2023 and 2024, ensuring that the analysis reflects the latest developments and trends.

2 *Identification of research gaps and future directions*: This study identifies specific gaps in the existing literature, such as the need for more research on the integration of technological solutions in humanitarian logistics and the importance of local-global coordination. It also outlines clear directions for future research, helping to guide subsequent studies in addressing these critical areas.

3 *Framework for resilience and sustainability*: This review advances the theoretical understanding of these concepts in the context of HSCs by proposing a comprehensive framework that integrates resilience and sustainability. This framework can serve as a foundation for future empirical studies and practical applications.

4 *Enhanced focus on pandemic-specific challenges*: This study specifically addresses the unique challenges posed by the COVID-19 pandemic unlike earlier reviews that may have focused on general disaster management. It provides insights into preparation of SCs for global health crises in the future.

Thus, the present review significantly advances the understanding of HSCs during pandemics by synthesising insights from recent studies and highlighting key areas for future research. The novel contributions and practical strategies offered in this study will serve as a valuable resource for researchers, policymakers, and practitioners in the field of humanitarian logistics and SCM, ensuring that vulnerable populations receive timely aid in future pandemics.

1.2 Motivation from industry and academic perspectives

From an industry perspective, the motivation for this study stems from the need to enhance the efficiency and resilience of SCs during pandemics. The disruptions caused by COVID-19 highlighted significant vulnerabilities in current HSC frameworks. These disruptions impact the timely delivery of essential goods and services. Also, industries involved in logistics, healthcare, and disaster management are keen to adopt innovative solutions and methodologies to address these challenges. Thus, enhancing the robustness of HSCs not only improves crisis response but also ensures continuity of operations, which is vital for economic stability and public health.

From an academic perspective, there is a pressing need to systematically analyse and synthesise the vast amount of research on HSCs. Although numerous studies have addressed various aspects of humanitarian logistics, there is a lack of comprehensive reviews that consolidate these findings in the context of pandemics. The present paper seeks to fill this gap by critically evaluating over 150 articles published between 1992 and 2023. The goal is to provide a structured overview of the field, identify important trends, and highlight areas where further research is needed. By doing so, this study aims to guide future research efforts, fostering the development of more effective and resilient HSC frameworks.

1.3 Research questions

The present study is guided by several important research questions. These questions are aimed at providing a thorough understanding of the HSC framework in the context of pandemics:

1 What are the most critical factors influencing the efficiency and resilience of HSCs during pandemics?

2 How have different distribution strategies been utilised and their effectiveness evaluated in past pandemics?

3 What role do artificial intelligence (AI) and advanced technologies play in enhancing HSCs?

4 What are the current gaps in the literature regarding HSC frameworks in the context of pandemics?

5 What innovative solutions and methodologies have been proposed to address the challenges faced by HSCs?

Thus, the present paper aims to offer valuable insights and a foundation for future research and practice in the field of humanitarian logistics by addressing these questions.

1.4 Identification of relevant articles

The identification of the 150 articles reviewed in this paper was conducted through a systematic literature search. Databases such as Scopus, Web of Science, and Google Scholar were utilised to collect relevant articles published between 1992 and 2023. Keywords and phrases related to 'humanitarian supply chain', 'pandemic logistics', 'disaster relief logistics', 'supply chain resilience', and 'crisis management' were employed in the search. The initial search results were filtered based on relevance, peer-review status, and citation metrics. Duplicate articles were removed, and the remaining articles were further screened by reading the abstracts to ensure they met the inclusion criteria. This rigorous selection process ensured perfect sample of the existing literature.

1.5 Research opportunities

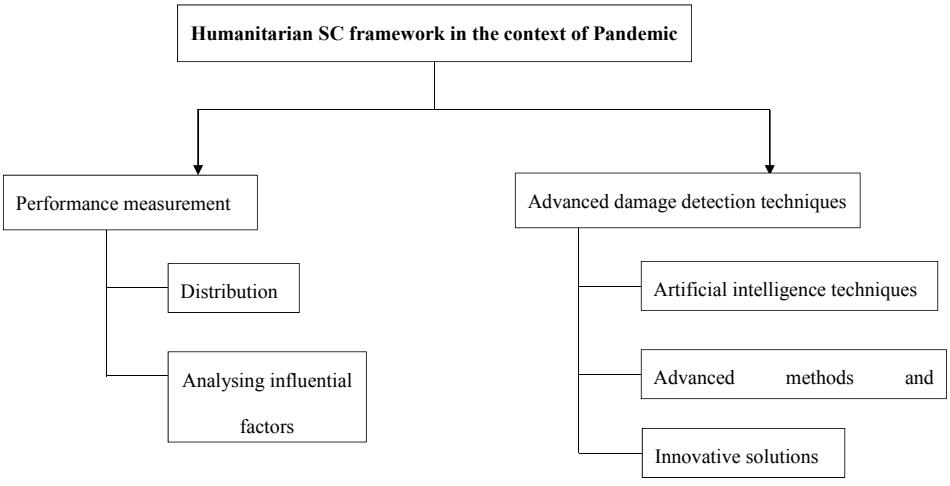
The review identifies several research opportunities that could significantly advance the field of HSC management. One important area is the development of integrated frameworks that combine traditional logistics with emerging technologies such as blockchain and Internet of Things (IoT) to enhance transparency and traceability. Another opportunity lies in the application of machine learning and AI to predict supply chain disruptions and optimise resource allocation. Additionally, there is a need for more empirical studies that evaluate the effectiveness of different SC strategies in real-world pandemic scenarios. Research into collaborative models involving public-private partnerships can also provide insights into improving coordination and resource sharing. Lastly, the exploration of sustainable practices in HSCs to minimise environmental impact while maintaining efficiency remains an under-researched area having significant potential.

1.6 Proposed methodology of literature review

This review examines the existing literature on various aspects of the HSC, including supply chain design and planning, SCM strategies and logistics, and digital transformation. Furthermore, the review identifies the challenges in the HSCs. The literature review is divided in 2 major sections that comprise survey of articles from theory to practical orientation as shown in Figure 2. Section 2 discusses the Performance measurement in HSCs which includes Distribution and Analysing influential factors. Then, several solution techniques of HSCs such as use of AI, advanced methods and framework, and innovative solutions are described in Section 3. Scope for future research

is given in Section 4. Finally, conclusion of review is given in last section. The paper concludes by highlighting the need for an integrated and collaborative approach to managing the HSCs during pandemics.

Figure 2 Proposed methodology of literature review



2 Performance measurement

This section discusses various performance measurement measures in HSCs. Initially, literature pertaining to distribution of supplies is discussed, after which review of articles related to factors affecting SCs is given.

2.1 Distribution

While considering the effectiveness of a HSC structure in the context of a pandemic, distribution is an extremely important factor to take into account. It is necessary that help and resources be sent to impacted communities in a manner that is both efficient and timely to ensure that the response is as successful as possible. Within the scope of this study, a number of factors of distribution that have an impact on the efficiency with which the SC is measured. The first step, which is also the most important, is to set up distribution networks and infrastructure. The timely distribution of relief may be facilitated by well-designed networks that take into consideration their closeness to impacted regions, various means of transportation, and storage facilities. Second, one of the most important aspects of the distribution process is the coordination and cooperation that exists between the many parties that are engaged. The effective coordination of distribution efforts is enabled by the close collaboration of humanitarian organisations, government agencies, and local communities. Thirdly, another important factor is the convenience and accessibility of the available modes of transportation. It is essential to locate alternate travel corridors and modes of transportation because the pandemic has the potential to disrupt transportation networks. Fourthly, one of the most important considerations is the 'last-mile distribution', which refers to the act of bringing relief

directly to the people who have been impacted. To guarantee that help is distributed to the people who are supposed to receive it calls for meticulous planning and organisation. Further, it is necessary to use technology and methods that are driven by data in order to monitor and track the activities involved in distribution. The visibility of events as they occur in real-time enables improved decision-making, resource allocation, and the detection of bottlenecks in the distribution process. In conclusion, an efficient distribution strategy is essential for gauging the effectiveness of a HSC framework in the context of a pandemic. Important variables to take into account include network architecture, coordination, transportation, last-mile distribution, and monitoring.

Vaccines are generally acknowledged as an essential tool for preventing infectious illnesses in communities. Distribution of vaccine is important constituent of supply chain in the times of pandemic. Khodaee et al. (2022) proposed comprehensive approach to eliminate infection and death rates while minimising all expenses incurred, including transit costs, shortage costs, deprivation costs, and holding costs. Their suggested model can assist decision-makers in implementing a distribution of vaccinations and better understanding the value of equity. Researchers also demonstrated differentiation between vaccines and commodities and explained the major concerns with designing the SC for vaccines. In order to determine whether these models are applicable to SCs for vaccines, the research evaluated the literature on model-based supply chain network design (Lemmens et al., 2016). Scientists studied the literature on logistics for vaccines and pinpointed promising areas for future study. Four categories were used to categorise the literature were product, production, allocation, and distribution. They also examined the dilemmas associated with choosing between sudden and ongoing epidemics within the supply chain classification (Duijzer et al., 2018). Their analysis covered 23 works, including theses and peer-reviewed articles. Academic databases like Emerald-insight, Wiley, SpringerLink, Google Scholar, ScienceDirect, and Taylor and Francis were used to screen the papers (Polater, 2018). Low-performing SCs pose hazards that jeopardise the security and efficacy of vaccines. In order to develop strategies to enhance vaccine SCs globally, it is crucial for vaccine producers to participate actively in forums for all relevant global stakeholders (Jarrett et al., 2020).

To improve vaccination and treatment access, justice, and equity, recommendations are being developed by a Lancet Commission for COVID-19 task committee. That entailed establishing reliable worldwide pharmacovigilance and surveillance systems to guarantee safety and efficacy. Vaccines must be routed through World Health Organisation (WHO) prequalification and emergency use listing systems in order to be compliant with global product quality standards (Hotez et al., 2021). Vaccine reluctance and unequal vaccine distribution are a couple of the problems that have hindered immunisation campaigns. These difficulties emphasise the requirement for an effective COVID-19 mass vaccination effort. Nahofti Kohneh et al. (2023) made an attempt to find a solution to this problem by developing a system for the integrated and bi-objective allocation of vaccines and inventory management. The development of a framework for analysing the efficiency of the humanitarian medical supply chain (HMSC) uses academic and professional literature. The results of expert interviews and a case study of a significant humanitarian medical crisis are used to validate the framework of Ebola outbreak in 2014 (Dolinskaya et al., 2018). According to the findings of the research, there are 15 different enablers of the emergency supply chain in the healthcare sector. These enablers have also been verified. Based on the driving and dependent capacities of enablers, a seven-level hierarchical structural model has been built. The classification of

enablement into four groups is the result of the analysis of the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis (Hossain et al., 2022).

At the supply, demand, and logistics ends of the supply chain for agriculture, resilience can be increased by a variety of proactive and reactive techniques such cooperation, coordination, information and communications technology (ICT), and ground-level inputs. Maintaining operational excellence during a pandemic is also reported to be difficult due to senior management's lack of commitment and assistance (Mishra et al., 2022). The findings indicated that there are various interruptions in the supply of cosmetics and personal care items for merchants. These include inconsistent product delivery, limited credit availability, supplier payment interruption, product shortage, and limited delivery service. Retailers can employ a number of strategies to reduce the effects of interruptions and improve supply resilience, including close communication and cooperation, the creation of an adjusted credit ratio, and a preference for product availability over brand preference (Chowdhury et al., 2020).

The coronavirus pandemic's effects on changes in food insecurity were first estimated in a low-income nation. Prior to the pandemic, food insecurity was more common in rural households. Three months after the epidemic began, there was no longer any difference between urban and rural areas in terms of food insecurity (Adjognon et al., 2021). The HSC framework is also important for equitable distribution of aid. It ensures that resources are allocated fairly and equitably, with a focus on reaching those in the greatest need. This is achieved by better understanding the needs of the people, identifying the most effective and efficient distribution channels, and leveraging the power of technology and data to better target resources. Thus, the HSC framework helps to ensure that aid is delivered in a timely and appropriate manner and that it reaches those who are most in need by focusing on the needs of the people.

2.2 Analysing influential factors

In the context of a pandemic, the performance monitoring of HSC frameworks has developed into an extremely important topic of research. In order to guarantee an effective and efficient reaction during times of crisis, several relevant aspects need to be taken into consideration. The purpose of this review is to investigate these elements in more detail and to shed light on the influence that they have on the assessment of the overall performance. To begin, one of the most important factors is whether or not required resources are readily available and easy to obtain. It is very necessary to have sufficient stocks of PPEs, medical supplies, and other important materials in order to react immediately. Second, it is of the utmost importance for all of the many players, such as governments, non-governmental organisations, and local communities, to work together and coordinate their efforts. In order to improve coordination, it is necessary to build efficient communication routes as well as systems for the exchange of information. Thirdly, the capacity of supply chain systems to adapt and remain resilient is going to be very important during a pandemic. The prompt and effective distribution of help is ensured by the flexibility of its delivery routes, means of transportation, and storage facilities. Fourthly, the use of technology and decision-making processes that are driven by data assists in real-time monitoring, tracking, and forecasting of patterns of demand and supply. In conclusion, the quantity of financial resources that are allotted to the framework of the HSC has a substantial influence on the functioning of the framework. It is crucial to get sufficient financing in order to finance the essential infrastructure,

logistical, and manpower requirements for a successful response. When it comes to the overall picture, having a full grasp of these relevant aspects is very necessary in order to develop and assess the success of HSC frameworks in the context of a pandemic.

The COVID-19 pandemic reveals SCs' previously undiscovered vulnerabilities. SCs and the shocks that follow them are primarily stressed by disruption propagation via connected networks. The data showed that the most important factor in managing SCs during pandemic disruptions is the ability to adapt (Ivanov and Dolgui, 2021). The purpose of the study by Cordeiro et al. (2022) was to determine how pandemic affect SCs' resilience during outbreaks. An improved comprehension of the state-of-the-art in pandemic breakouts resulted from the review. The results can be used as the foundation for public policies that guarantee higher resilience. In light of the pandemic situation in SC, the purpose of the article by Rajak et al. (2022) was to identify the demands and critical success factors (CSFs) for the initiative for sustainability. Social exclusion, emergency backup facilities, and emergency logistics systems are all examples of CSFs.

Supply networks are facing greater challenges than ever before as a result of the COVID-19 epidemic. In the UK market for perishable commodities, the study carried out by Ozdemir et al. (2022) sought to evaluate how existing solutions promoted SCR. The most important aspect was innovation, which was followed by resilience, empowerment, and risk management through lower risk. The most crucial factor determining the resilience of the hotel and tourism industries has been discovered by the researchers, and the results will assist in managing and minimising the COVID-19 pandemic's effects. SC visibility is the most important component in constructing the resilience of hotel and tourism supply chain (HTSC) out of all the vital success elements (Jain et al., 2022). The worldwide economy has been negatively impacted by the COVID-19 pandemic. Global supply chains have reached their breaking point as a result of the implications of such effects. Industries that directly face these key obstacles have been identified by scientists. According to the findings, the biggest obstacle influencing businesses is a lack of inventory (Gamal et al., 2022).

Increasingly, humanitarian groups must overcome obstacles to increase the effectiveness and efficiency of their disaster assistance initiatives. These problems are typically due to lack of communication, insufficient coordination, and an inability to immediately reach regions that have been damaged by a catastrophe. Dubey et al. (2022) comprehended how humanitarian actors' quick trust, dedication, and teamwork increase the supply chains' agility. Researchers searched scientific databases and preprint servers for publications that address the COVID-19 pandemic, as well as individual or social vulnerabilities. Decisions about eligibility and the extraction of essential data were made by reviewers who were not affiliated with one another. The findings were evaluated thematically to determine whether or not the hazards faced by persons with impairments and other types of vulnerability are disproportionate (Jesus et al., 2020). According to the (Sharma et al., 2022), visibility is positively influenced by information sharing by customers and SC traceability. Visibility also has a favourable impact on the adoption of environmentally responsible practises and velocity, both of which contribute to an increase in the SC's overall effectiveness. When information is shared with the supplier, there is no noticeable influence on visibility, whereas when information is shared with the customer, there is no visible impact on performance.

Researchers analyse the US disaster response system's operational and functional performance. Highlights of the work include an overview of the National Incident Management System and Incident Command System, local and state response capacity,

volunteer group response mechanisms, legislative and budgetary difficulties, and local and state response capabilities. The National Disaster Recovery Framework (NDRF) and many services offered to aid in recovery are also described by the author (Bullock et al., 2021). An increasing focus on food science and technology that addresses local food security, creates jobs, and boosts the local economy is necessary for transformation to embrace innovation across the entire food system. Instead of bolstering local food systems and ensuring resilience, emergency initiatives and projects often lead to dependency on help (Bounie et al., 2020). Numerous organisations have been compelled to undertake major change as a result of the COVID-19 epidemic. A common understanding of the major problems and underlying difficulties impacting organisations and society is provided in the study by Dwivedi et al. (2020). The professional viewpoints provided timely analysis of a wide range of subjects and recommendations for theory and practise. The Saudi government showed the highest level of accountability by placing a strong priority on the security and welfare of its residents and citizens. The prompt reaction to pandemic warnings, tremendous knowledge of previous epidemics and mass drug collection, wise use of healthcare resources, and unprecedented collaboration between the public and business sectors were all significant components to this accomplishment (AlFattani et al., 2021).

One of the area's most at risk from the severe effects of climate change and related disasters is the Asia-Pacific. The agendas of local authorities should give priority to disaster risk reduction (DRR). The study by Uchiyama et al. (2021) reviewed and evaluated a number of disaster risks that were the subject of local projects. The COVID-19 pandemic has aggravated the terrible humanitarian crisis brought on by the Rohingya refugee crisis. Findings indicated that Rohingya households were significantly more vulnerable than households in the host community. Compared to 2% of host households, nearly 65% of Rohingya households were classified as 'acutely vulnerable' (Nasar et al., 2022). The food bank supply chain is investigated during the turmoil of 2018–2020 brought on by the COVID-19 epidemic and the US–China trade war. The trade war responses used flexible capabilities and cost-effective innovation to increase resilience during the epidemic. Broader insights for business-to-business companies were generated from the specific findings for food banks (Blessley and Mudambi, 2022). Due to the COVID-19 pandemic's impact on perishable food supply chains (PFSCs), certain countries are finding it difficult to meet consumer demand. The goal of the study by Shanker et al. (2022) was to strengthen PFSCs' resilience by analysing the factors influencing them during the pandemic.

The results of the study by Nasir et al. (2022) showed that the establishment of a digital SC twin and the transformation of SCs into supply networks would assist policymakers in adjusting to the 'new normal', and that SC crowdfunding and the development of health protocol policy are important influencing factors for supply chain viability (SCV). Global supply chains have been impacted by the COVID-19 epidemic at an unprecedented rate and scope. The difficulties that businesses have encountered with their supply chains are examined in the study by Raj et al. (2022). The biggest problem is a lack of labour, closely followed by a lack of materials. Measuring the effectiveness of the supply chain for humanitarian aid has been a growing area of inquiry. The review by Anjomshoae et al. (2022) aims to establish a connection between the ideas and trends in the larger field of performance evaluation and the particular problems experienced in providing humanitarian relief. The results are confined to peer-reviewed journals concentrating on supply chain and operations management literature. The Oman's small

and medium enterprises' (SMEs) supply chain drivers and general performance have been impacted by the COVID-19 outbreak. Statistical analysis tools SPSS and PLS were used to examine the data. The model has empirical backing, and the findings indicated a significant link between Oman's supply chain driver and overall performance (Abdelfattah et al., 2023). The increase is a result of a new COVID-19 outbreak inflection point. Their study attempts to examine and evaluate supply chain hazards, particularly those related to medical goods. The research shows that prompt planning and evaluation of supply chain risk can lead to precise adoption of strategies (Safa et al., 2021). A study by Shahed et al. (2021) created a mathematical model to lessen the impact of natural disasters like the pandemic on a three-stage (supplier, manufacturer, retailer) supply chain network. The manufacturer is given the best option by the proposed inventory-based disruption risk mitigation methodology to optimise profitability. The purpose of the study by Karuppiah et al. (2021) was to identify and assess the obstacles to managing a sustainable humanitarian supply chain (SHSC). The results showed that five major hurdles in SHSC during COVID-19 include issues with facility location, short lead times for emergency supplies, the propagation of rumours, and uncertainty about the available treatment. Public-private partnerships are thought to be the most effective approach to overcoming these difficulties.

The following factors are key to the success of the HSC framework:

- *Collaboration*: Establishing and maintaining effective partnerships with other stakeholders is essential for successful humanitarian aid delivery. This includes other international agencies, governments, donors, and non-government organisations (NGOs).
- *Risk management*: Effective risk management is important for reducing the chances of errors or delays in aid delivery.
- *Data analysis*: The effective use of data can help to inform decision-making, optimise operations, and ensure equitable distribution of aid.
- *Technology*: Leveraging the power of technology can help to improve the efficiency and effectiveness of aid delivery.
- *Transparency*: Ensuring transparency in the HSC helps to ensure that resources are used appropriately and equitably. It also helps to create an environment of trust between the different stakeholders.
- *Sustainability*: The HSC framework should be designed to be sustainable in the long term. This includes establishing appropriate systems and processes, and ensuring that the framework is resilient in the face of future shocks.

3 Solutions

Table 1 lists obstacles in sustainable humanitarian SCM. These obstacles can be overcome by using advanced and innovative techniques such as AI, big data analytics etc.

Table 1 Obstacles in sustainable humanitarian SCM

Researchers	*Obstacles*	*Elaboration*
Smarandache (n.d.)	Shortage of skilled volunteers and workers	There are not enough paramedics on staff to effectively address the problem
Gomes and Lima (1992)	Head of the monitoring committee is replaced	Frequently, the monitoring committee's head shifting causes difficulties in the proper information flow
Ghorbani and Ramezanian (2020)	Ineffective coordination	It is challenging to develop cooperation among supply chain network participants due to the monitoring committee's frequent changes in leadership
Adobor (2019)	Lack of separation of duties	Task delegation issues lead to misunderstanding and may affect the desired result
Safarpour et al. (2020)	Lack of specialists in managing pandemics	A new employee's difficulties handling and making decisions
Yadav and Barve (2016)	Uncertainty regarding the offered cure	Fear over the effectiveness of the offered treatment discourages people from taking the medication
Wagner et al. (2021)	Influence of the region's socioeconomic and political situation	The efficiency of the supply chain network is influenced by the local conditions in the country or region
Huda et al. (2020)	People's lack of awareness	Insufficient familiarity with humanitarian groups and activities
Ghasemian Sahebi et al. (2017)	Rumours are spread	False information makes the public anxious
Ghorbani and Ramezanian (2020)	Inadequate telecommunications and information infrastructure	The impact of the problem is exacerbated by the lack of cutting-edge information communication systems

3.1 Artificial intelligence techniques

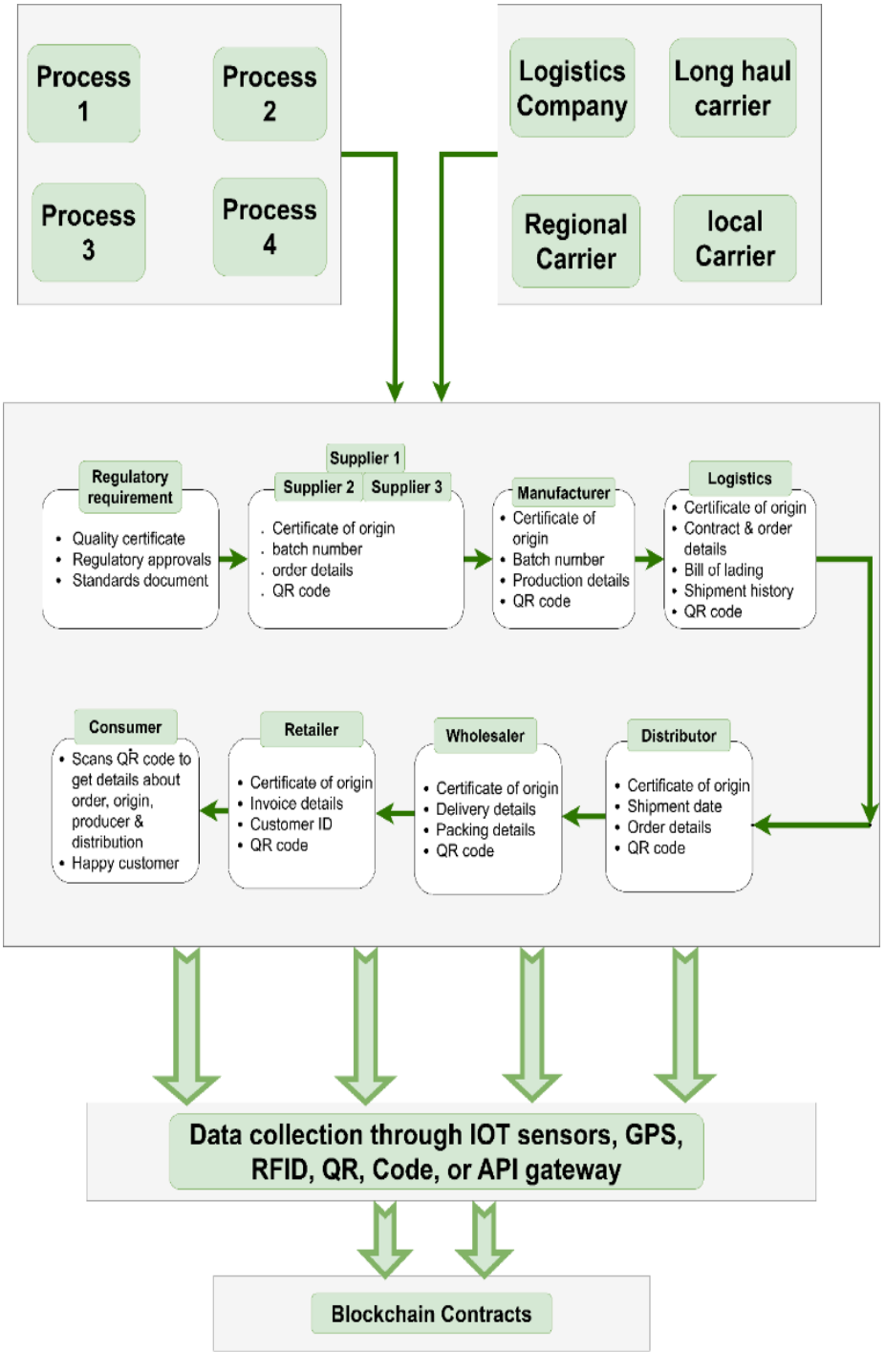
Several researchers have using AI techniques such as machine learning and big data analytics (BDA) to overcome obstacles in humanitarian SCM. The COVID-19 pandemic outbreak has permanently altered the way we work and live. Different business models are being developed to deal with life after the crisis. By suggesting scenario planning and analytics for large information technology-driven enterprises, the study performed by Hajipour et al. (2021) seeks to close this gap. According to the findings of a research conducted by Nayal et al. (2022), process factors, information exchange, and supply chain integration (SCI) each have a substantial influence on the adoption of AI, which has a beneficial impact on SCRM. It is not accurate to say that there is a substantial inverse link between AI and the organisational, technical, or environmental aspects. A multi-objective optimisation model developed by Ashtab and Tosarkani (2023) for plastic closed loop supply chain configuration examined the effect of corporations' role in consumer awareness and the addition of washing machines to recovery centres on recycling costs and CO_2 emissions. The results indicated that the integration of these factors can decrease design costs by 3.93% and CO_2 emissions by 14.24%, thereby promoting sustainability.

Researchers also discovered that SC analytics powered by AI, along with alliance management skills, improves the organisation's operational and financial performance (Dubey et al., 2021). Also, there appears to be a lack of decision support to address the problems associated with epidemic outbreaks in underdeveloped nations. The dataset presented in the study by Anparasan and Lejeune (2018) can be used to create allocation models and strategies for an epidemic outbreak. Organisations need to be adaptable and resilient in order to handle unforeseen situations like disasters. Humanitarian organisations are still hesitant to adopt BDA powered by AI. A practice-based perspective can help people understand HSCs better (Dubey et al., 2022a). Researchers from the University of Aberdeen in Scotland believed that digitalisation could be a crucial tool for enhancing the efficacy of SCR solutions (Pellegrino et al., 2022). The results of their study can help managers create straight forward and traceable models for determining how different SC disruption sources are interdependent. Further, scientists discovered that SC analytics powered by AI, along with alliance management skills, improves the organisation's operational and financial performance (Dubey et al., 2021).

The worldviews underlying AI have changed as a result of the current global instability, which includes demographic inversion, war and human displacement, protectionist beliefs, ecological and energy concerns, and demographic inversion (Farrow, 2019). In terms of preparing for probable hurricane activity, a stochastic inventory control problem is relevant to proactive disaster recovery planning. In comparison to earlier stages of the planning horizon, later stages can more accurately predict hurricane characteristics. The problem-solving algorithm is characterised as dynamic programming (Lodree and Taskin, 2009). Digital technologies (DTs) are quickly assimilating into everyday life. The primary task of DTs is processing information, which is typically presented as binary code. Surprisingly, the COVID-19 pandemic has brought attention to the importance of DTs in people's lives (Mardani et al., 2020).

Blockchain is a cutting-edge technology that combines a variety of distinctive properties, including decentralised organisation, distributed note-taking and storage, consensus algorithm, smart contracts, and asymmetric encryption. Solutions based on blockchain technology have the potential to effectively reorganise a variety of sectors, including shipping, manufacturing, automotive, aviation, finance, technology, energy, healthcare, agriculture and food, online retailing, and education, amongst others (Dutta et al., 2020). Despite the introduction of vaccinations, the COVID-19 coronavirus disease continues to pose difficult problems. Many nations continue to use policies like mandatory face masking, contact tracing, and social seclusion. Because of the potential for ethical principles to be violated, the use of digital technology has been controversial and divisive (Mbunge et al., 2021). During a pandemic, food supply chains (FSCs) are among the most crucial services. Perishable food supply chains (PFSC) face greater risks because they must contend with greater wastage and problems with product life cycles. The best-worst method (BWM) furry extension aids in incorporating fuzziness and ambiguity into the decision-making process (A. Kumar et al., 2021). The study by Belhadi et al. (2021) sheds light on how the COVID-19 epidemic affected the automotive and aviation SCs. The two SCs' short- and long-term response plans are evaluated. BDA was seen by both industries as having a substantial impact on overcoming the difficulties brought on by the pandemic. Application of blockchain in supply chain and logistics is shown in Figure 3.

Figure 3 Application of blockchain in supply chain and logistics (see online version for colours)



Lallie et al. (2021) investigated the COVID-19 pandemic from the point of view of cybercrime and provide an illustration of the several forms of cyberattacks that took place

all over the globe during the pandemic. The investigation proceeds to utilise the UK as a case study to explain how cyber-criminals leveraged important events and governmental statements to create and execute operations. In the face of widespread disruptions, a decision-making framework that is model-based is developed in order to facilitate the design of decentralised, networked production systems. The framework was established with the assistance of a case study that took place in South East England in the beginning stages of the COVID-19 pandemic epidemic. The results showed that putting the framework into practise helped production networks powered by additive manufacturing perform better (Haddad et al., 2021a). In the opinion piece, Nandi et al. (2021) offered lessons learned from the COVID-19 pandemic for strengthening, enhancing, and sustaining SCs. Using blockchain technology (BT) and the powers of the circular economy idea, they connected localisation, agility, and digitisation (LAD) to a potential resolution. The use cases are utilised to demonstrate how blockchain-enabled circular economy practises might aid LAD initiatives. Indian Smart Cities claim that they were able to control the COVID-19 outbreak better than other urban areas. The underutilisation of numerous initiatives started during the pandemic was caused by the lack of measures to connect marginalised persons with Information and Communication Technologies (ICTs) through the Smart City Mission policy (Mullick and Patnaik, 2022). Discussions about the use of BT in SCM are increasingly common. In their study, the scholarly literature and the media on BT-enabled SCM are synthesised using data. Reverse logistics, closed-loop supply chains, and BT-enabled SCM were found to be significant research avenues (Sangari and Mashatan, 2022).

Concerns about vaccine expiration, inclusion of fake vaccinations, and vaccine record fraud continue to have an impact on vaccine supply chains. Full-scale deployment of BT in vaccination distribution and management has yet to be achieved. The biggest obstacles are a lack of technological know-how and a substantial IoT infrastructure (Yadav et al., 2023). During the epidemic, creating a digital humanitarian network is crucial. The effectiveness of humanitarian activities (HA) is increased through the usage of digital platforms for sharing real-time information. This study gives decision-makers, policy-makers, and stakeholders the chance to take these elements into account when strategising (Joshi et al., 2022). Researchers are becoming more interested in studying SCRs in manufacturing and service operations under changing conditions. Researchers are becoming more interested in studying SCRs in manufacturing and service operations under changing conditions. Also, BDA was playing a significant role by industries (Belhadi et al., 2021).

To get insightful conclusions, Kumar (2020) applied the model to a real-world scenario. They also looked at the trade-off between costs and benefits of using BT in a public distribution system (PDS) supply chain. The findings demonstrate that BT adoption in a non-profit supply chain can drastically lower theft and phantom demand. AI is increasingly being used to improve the effectiveness of the HSC. AI can help to identify complex patterns in data, optimise operations, and analyse risk. By leveraging AI, organisations can better target resources and ensure that aid reaches those who need it most. AI can also be used to optimise logistics and ensure the efficient delivery of aid. Furthermore, AI can be used to identify potential areas for improvement and ensure that the HSC is resilient in the face of future shocks. Overall, AI can be a powerful tool for improving the effectiveness of the HSC. By leveraging AI, organisations can better target resources, optimise operations, and ensure that aid reaches those who are most in need.

This can help to ensure that resources are used equitably, and that aid is delivered in a timely manner.

3.2 Advanced methods and frameworks

In order to evaluate, display, optimise, and simulate supply networks, Timperio et al. (2022) suggested a multi-method decision support system, Disaster Emergency Logistics System (DELSA). According to the findings, the DELSA network's performance in terms of service level is improved by 41% with the implementation of inventory management policies with safety stock. Many fatalities are caused by epidemic outbreaks. Rapid action is required for the effective management of an epidemic outbreak. The creation and management of an emergency SC are crucial. In order to help control outbreaks, the study focuses on defining the function of logistics operations and their management (Dasaklis et al., 2012). Disaster relief efforts' primarily focus on providing aid to victims in need while paying little attention to their socioeconomic situation. The viewpoint must enlarge during the recovery phase after a disaster and take into consideration the local environment. Kunz and Gold (2017) suggested a paradigm for managing the sustainable HSCs that makes such thorough performance possible. A practical method for gauging the effectiveness of humanitarian operations is discussed by Anjomshoae et al. (2021). A hierarchical multi-stage fuzzy inference system (FIS) was created to deal with ambiguous and imprecise performance indicators. Practitioners from prestigious international humanitarian organisations in Malaysia tested and validated the scheme.

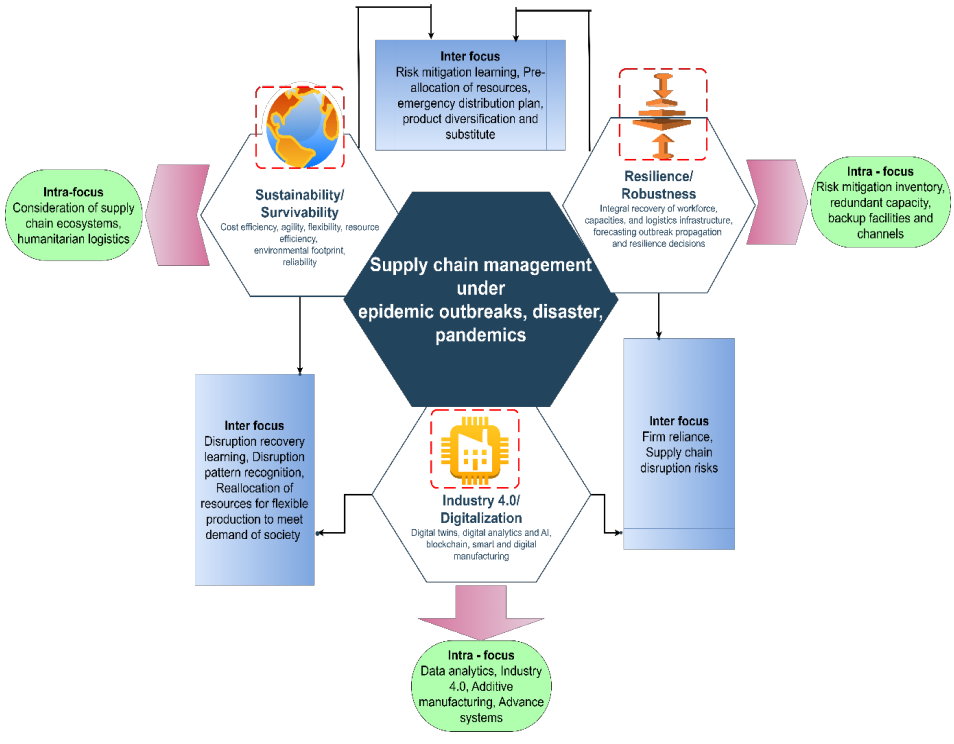
Global supply chains have been hampered by the COVID-19 pandemic's uncertainties. Now, the goal of decision-makers is to strike a balance between agile and lean systems. For the purpose of designing supply chains for a pandemic scenario, a mixed integer nonlinear programming model has been created (Antonio et al., 2022). When supply chains need to be built up promptly, collaboration in emergency logistics might be advantageous for governmental actors. Public-private emergency collaborations (PPEC) have not thoroughly studied. The development of a framework for public-private emergency partnerships is based on notions from game theory and logistics (Diehlmann et al., 2021). Researchers urge increased use of the framework for health-emergency disaster risk management (Health-EDRM). They also offer various suggestions, both general and specific to DRR (Djalante et al., 2020). An analytical technique based on binary choice diagrams has been suggested in research to simplify the computation of Birnbaum importance for supply chain fault risks. The findings demonstrated that the proposed technique offers a practical methodology for assessing each supply chain risk, which is utilised to pinpoint flaws and lower risks (Li and Xue, 2019). Figure 4 shows framework for readiness of SCs to combat pandemic.

Business continuity management (BCM) is a crucial element of a company's competitiveness. Decision support can be extremely valuable if corporate activities are significantly disrupted. In their study, a unique decision support mechanism is presented by Schätter et al. (2019) that results in a better, more reliable BCM for major interruptions brought on by disasters. The WHO model leaves out significant predictors of tuberculosis (TB) incidence like war, civil unrest, and significant upheaval like large evictions in rural and urban areas. The study by Wallace and Wallace (2019) looks at institutional efficacy and efficiency in pandemic disease control under unclear circumstances caused by unbalanced power relations at the community level. In order to

deal with demand and supply uncertainty and avoid inventory stock-outs, safety stocks are an appropriate strategy. This is the first comprehensive analysis of the use of operational research (OR)-based methods to research this issue. To determine the kind of model being used, 95 papers from the years 1977 to 2019 have been examined by researchers (Gonçalves et al., 2020). Numerous scholars from around the world who put forward description models study SCs. The Liquid Supply Chain (LiSC) is a novel supply chain concept that is described in the study by Passarelli et al. (2021). It also considers the remarkable results of the COVID-19 virus's pandemic spread. When supply chains need to be built up promptly, collaboration in emergency logistics might be advantageous for governmental actors. A framework for multi-attribute reverse auction is presented in a paper to make it easier for suppliers and a relief organisation to conduct purchasing operations. The relief organisation informs vendors of demand and necessary relief supplies during the announcement phase. The winner(s) and orders are then determined by solving a fuzzy tri-objective mathematical model (Khoshsirat et al., 2021). One of the most important strategic choices in SCM is supply chain network design (SCND). Modelling disruption risk is one area of SCND in particular. The costs especially brought on by disruption risks and resilience investments are the subject of the investigation. In the relevant literature, shortcomings and details are highlighted by Aldrighetti et al. (2021). During major crises, even SCs that appear to be well-oiled may be subject to hiccups. Local production may offer a backup method of meeting local needs due to the efforts and resources of nearby businesses and individuals. The goal of the study by Haddad et al. (2021b) was to create a framework for decision-making for the design of local manufacturing networks with AM capabilities. Many non-pharmaceutical businesses in India are producing PPEs at a very low volume. Therefore, Ahmad et al. (2021) developed a modelling and optimisation framework for waste management and sustainable production. According to the findings, product-based service (PBS) supply chain disruptions should be classified as either unmanageable external supply-side, demand-side, or interactional disruptions or as other manageable forced or forced organisational disruptions.

Gatenholm and Halldórsson (2023) then created a conceptual framework that combined resilience and transformation into new service opportunities in response to that characterisation. A thorough analysis of the literature on supply chain performance measurement in relation to several industry 4.0 technologies has been conducted. Since there are few research currently available, the study by Govindan et al. (2022) used case studies to validate the suggested framework. The study takes into account the aspects of manufacturing, procurement, logistics, warehousing, and construction. The investigation resulted in the creation of a Fuzzy interpretive structural modelling (FISM) model, where the performance-affecting operational difficulties are at the very top of the hierarchy. The findings showed that inconsistent motivation, poor coordination and communication, and operational challenges affecting performance are dependent, while poor strategic planning, capacity-related issues, and a weak performance measurement system are autonomous and independent barriers, respectively (Abbas et al., 2022). Vivaldini and Iglesias (2022) outlined a model, that was used to carry out the aid operations, depicted the HSC used by the cultural centre, explained the linkages and operations established, and contrasts the business procedures with those used by commercial chains. Initiatives and possibilities that could help commercial entities get more involved in humanitarian work are reviewed.

Figure 4 Framework for readiness of SCs to combat pandemic (see online version for colours)



The COVID-19 pandemic has put SCs through unprecedented testing of their adaptability and viability in the face of extreme uncertainty. There is currently a dearth of literature on adaption tactics and the quantification of their effects. Four adaption techniques to ensure SC viability in a pandemic are generalised by Ivanov (2022). According to the system dynamics (SD) model for pandemics, initial supply-chain interruptions result in delays and shortages that spread across the chain. If these problems are not fixed right away, they can persist and cause shortages of PPE and other essential supplies just as a pandemic is starting (Falagara Sigala et al., 2022). The Haddon matrix aids in breaking down the difficulties in epidemic containment into more manageable parts. The study by Anparasan and Lejeune (2017) demonstrated how the matrix facilitates the visualisation of historical facts, aids in the analysis of multiple informational sources, and fosters cooperation among humanitarian groups. It will also provide as a foundation for scholars to develop new lines of inquiry to address epidemic outbreaks. A SC's viability refers to its capacity to sustain itself and endure in a dynamic environment. Ivanov (2022) proposed a novel idea: the viable supply chain (VSC). For the purpose of designing SCs that can respond adaptively to both positive and negative developments, decision-makers may find the VSC model useful. The primary requirement for boosting retail supply chain (RSC) performance in a dynamic social context, according to the current study, is 'Collaboration Efficiency'. The study also comes to the conclusion that 'Order Fulfilment' and 'Digital RSCs' are the best resilient business methods to lessen the long-term effects (Sharma et al., 2021). The study demonstrated that in order to develop a transparent, efficient, effective, and sustainable disaster supply chain management

(SDSCM) process for relief operations in Bangladesh, consideration must be given to a number of factors, including organisational capabilities, warehouse locations and inventory management, infrastructure facilities, coordination among partners, and support from the government and local authorities. System flaws can be located and fixed on the basis of these elements (Tasnim et al., 2022).

According to the findings of the research, there are eight components that are critical to the ability for adaptation of logistics service providers (LSPs) and, as a result, to their resilience when faced with challenging conditions. The findings of this research indicate that the aforementioned factors influence the reliability and adaptability of an SCRM system to the extent that it enables an LSP to anticipate any interruption and respond expeditiously to it (Hohenstein, 2022). Due to the COVID-19 disruption, the quickly shifting business climate, and supply network complexity, supply chains may be subject to disruptions and monetary losses. In the worst circumstances, it results in the closure of a business. The study by Joshi and Sharma (2022) presented a conceptual framework for assessing dynamic performance and sustainable practises. Governments, state authorities, and private parties were forced to plan and create the post-unlock operational procedures as pandemic COVID-19 permanently closed these places of worship. The authors developed a framework for the efficient movement of people and other services along this supply chain as a result of their way of thinking (Mittal and Sinha, 2022). The study suggests that in order to improve the resilience of PPE, SCs during pandemics, healthcare practitioners should employ an optimisation approach that is distributionally resilient. It emphasises how crucial monitoring and early warning systems are for enabling decision-makers to activate backup plans like locking down contracts, bolstering logistical capabilities, and using emergency stocks (Ash et al., 2022).

Analysts must also pay attention to the actors' developing situational awareness and their erratic motivations. Five overarching themes can be used to summarise developments in 23 different nations and practitioners' learning about supply and procurement throughout the pandemic crisis. They include problems with SCM, knowledge and skill gaps, information systems, and governance and organisation (Harland et al., 2021). The breakouts of locust swarms and COVID-19 pose a serious threat to the world's food supplies. This study's major goal is to comprehend and recognise the crisis' disturbances. It tries to develop a blueprint of how resilience might be built in order to restore and maintain the food supply system (Xu et al., 2021). With regular political, religious, and social change, the field of catastrophe management has grown in importance. The number of new works in the field of humanitarian logistics and supply chain research has significantly increased. Chiappetta Jabbour et al. (2019) charted a systematisation of this collection of knowledge by applying a system of codes and classifications to it. The authors discovered that the Emergency Response Unit (ERU) idea utilises a variety of standards that support and affect one another and that the emphasis on modularity is developing as a result of an increased demand for responsiveness. The main issues are trade-offs between autonomy and context-awareness that led to further modularisation and may jeopardise the notion (Jahre and Fabbe-Costes, 2015). Global SCs are largely disrupted by an infectious breakout due to declining corporate confidence. The coronavirus disease outbreak reached pandemic proportions in March 2020, and numerous millions of cases were confirmed globally. Based on the model's R0, this study proposes an action plan for minimising disruption in the SC (Jha et al., 2023). The COVID-19 virus pandemic that killed many people has significantly harmed the economy. This study emphasises the value of a pandemic supply chain with

high resilience. Singh et al. (2021) suggested a simulation model, that can aid in creating a flexible FSC to accommodate changing demand and then help in rerouting the vehicles in accordance with those constraints.

To decide how to best allocate scarce resources, commodities, or capital in a crisis, effective climate change adaptation strategies are required. The process graph model is a graph-theoretic method that was initially created for applications in chemical process design. The creation of disaster preparedness plans for anticipated disruptions and the implementation of real-time emergency response during a crisis are examples of potential applications (Aviso et al., 2015).

3.3 Innovative solutions

For organisations to face unforeseen circumstances like disasters, they must be flexible and resilient (Anjomshoae et al., 2022). People can better comprehend HSCs by adopting a practice-based viewpoint. Disasters emphasise the necessity of the HSC to assist those in need and the affected areas. Developing 'swift trust' and 'coordination' between assistance organisations are the key obstacles to implementing efficient relief operations. Implementing Industry 4.0 makes it easier for HSC performance to coordinate and build trust quickly (Shayganmehr et al., 2021). A new kind of SC immunity based on visibility, velocity, and global independence has been established through study analysis. A responder to an emergency would presumably employ the framework for immunity' general principles informally. It is supported by citations to recent research on COVID-19 supply chain readiness (Handfield et al., 2022). In the context of the COVID-19 epidemic, this paper examines the effects of SC disaster readiness on SCR and SC robustness and the resultant impact on enterprises' financial performance. It offers a theoretical model that uses structural equation modelling to analyse data acquired from 398 French companies (Ruel and El Baz, 2023). An institution called the Logistics Cluster (LC) coordinates and directs national and international organisations to facilitate international humanitarian aid missions. Researchers carried out a qualitative content analysis of LC's and its supplier network members' activities. The results showed that the micro-foundations of sensing capabilities were anticipating demands in disaster-affected areas and lessons-learned exercises (Tabaklar et al., 2021).

An empirical study encompassing three industries crucial to the wellness of Finns – energy, healthcare, and water services – aims to advance our understanding of linked hazards. They achieved this by looking into the preparedness weaknesses that can worsen inter-sectoral cascades and how these weaknesses can be rectified (Kachali et al., 2018). As a means of assisting small and medium-sized businesses in the food sector (FSMEs) in their fight against the COVID-19 pandemic, the study provides both recommendations and a deeper understanding of SCR reactive procedures as potential options. Using the review's logical progression as a foundation, future directions are suggested as extensions (Ali et al., 2021). Three steps make up a review of 65 literatures: bibliometric analysis of Industry 4.0, supply chain transformation synergies, and state-of-the-art evaluation. The paper by Barata (2021) describes the current fourth supply chain revolution (4SC) and suggests directions for future study. The COVID-19 pandemic has raised awareness of contactless delivery and transportation options. In this context, drones offer a possible substitute, particularly for the delivery of necessities like virus tests. Utilising current drone infrastructure to complete this work is the unique method (Kunovjanek and Wankmüller, 2021). The COVID-19 pandemic provides a chance to examine how

previous disasters have strengthened the organisational resilience of Bali's tourism-related firms. It concludes that the Balinese tourism industry is vulnerable to future catastrophic occurrences because of the insufficient human and social capital that limits their organisational learning. For creating tourism firms that are robust to disasters, organisational learning is essential (Bhaskara and Filimonau, 2021).

An unparalleled global health disaster has been caused by the COVID-19 pandemic. Particularly vulnerable groups, such as breastfeeding mother-infant dyads, are in a precarious position. Aros-Vera et al. (2021) outlined operational principles and policy recommendations using a framework for disaster preparedness and response. All layers of SCs for perishable foods have been severely, unpredictably, and simultaneously impacted by the COVID-19 worldwide pandemic. Food security benefits from the important and quickly growing role of aquaculture. The sources of food insecurity, ripple effects, possible causes of disruption, and socioeconomic conflicts were found in survey replies (Mangano et al., 2022). The dose-response principle may be used to analyse a complex crisis scenario within a resilience-vulnerability framework. One, multi-layered risk management procedure should be used instead of several to deal with complex disasters. Health policies that anticipate how complex disasters may affect health risk management must offer countermeasures to prevent collapse and preserve resilience (Svetina et al., 2022). Ergonomics and human factors can help with crisis management, such as the COVID-19 pandemic. The Human Factors and Ergonomics (HFE) field needs to provide more expedient, less resource-intensive, but rigorous, methodologies. By expanding the field, it should expand the pool of HFE experts available and aggressively raise awareness of its significance among both individuals and the general public (Wooldridge et al., 2022). The purpose of their study was to present a conceptual framework with five steps for analysing how interactions between several hazards affect the built environment. A rigorous literature study and stakeholder workshops are part of the methodology. The framework can be used practically to develop decision-making checklists and focus next research needs (De Angeli et al., 2022). Given a fair measure of deprivation costs, the results suggest that it can be crucial for management should place more emphasis on the value of resources rather than their logistical expenses, minimising the general pain of the affected people as soon as possible. Additionally crucial for it is important for managers to understand that, despite the fact that deprivation costs and transportation costs are both rising as the time horizon lengthens, the deprivation costs' actual growth rate declines (Malmir and Zobel, 2021).

In the context of the Bangladeshi ready-made clothing sector, researchers tried to identify and model recovery issues. The data were analysed using a Delphi-based Grey DEMATEL technique. The study's conclusions can help policymakers create strategic plans to deal with recovery's problems (Paul et al., 2021). A branch of supply chain and operations management called 'humanitarian logistics and operations' focuses on how humanitarian organisations may distribute aid more effectively. (Keshvari Fard and Papier, 2023) compared the key traits of this industry to conventional supply chain and logistics management. Finally, they examined the extent to which the COVID-19 epidemic has compelled humanitarian groups to work in a non-traditional way when collaborating on projects. The ability of the PPE supply chain to offer adequate and consistent supply when there is a substantial rise in demand has not been well-considered. Infectious epidemics are rarely taken into account as potential humanitarian disasters in humanitarian literature. In their thesis, the gap between supply chain research and

epidemiology is filled using an exploratory case study and a system dynamics model (Gooding, 2016).

Patil et al. (2023) developed a framework to enable digitisation process of HSC after the end of COVID-19 pandemic. They identified 19 drivers for digitisation of HSC and confirmed them with stakeholders. They also used principal component analysis, Kappa analysis, and DEMATEL methodology to give preference to the identified drivers. (Bag et al., 2023) studied the effect of 'donor confidence in digital technology' and 'antifragility in HSC'. They observed that 'Trust in digital technologies' and 'perceived overall effective digital technology governance' played a moderating role. Also, HSC organisations can improve their effectiveness related to resources, hazards, planning using real-time data. In another study (Dubey, 2022b) explored the role of AI-driven big data analytics in humanitarian relief operations. They argued that traditional theories like resource-based or dynamic capability view are not suitable for understanding HSC performance. Therefore, they used a practice-based view to examine the role of practices that are easy to imitate in performance. The results showed that AI-BDAC significantly determinants of agility, resilience, and performance in the HSC. Further, they highlighted the need for a reduction in information complexity on the paths connecting agility, resilience, and performance. (Sahebi et al., 2020) reviewed barriers to blockchain adoption in HSC management using Fuzzy Delphi and BWM. They identified 14 barriers, out of which regulatory uncertainty, lack of knowledge/employee training, and high sustainability costs were the most significant. They also provided valuable guidelines for policymakers to optimise their solutions and improve the adoption of blockchain technology in HSCs.

Following is some of important points related to innovative solutions in humanitarian SCM:

a Utilising predictive analytics to predict and forecast the demand for goods and services. This will enable NGOs to efficiently plan and manage their supply chain, and determine the right amount of inventory and resources to be allocated for their operations.

b Leveraging digital technologies such as blockchain and IoT to enable real-time tracking, monitoring, and optimisation of goods and services in transit. This will help to ensure that goods reach the intended recipients on time and in the right condition.

c Developing automated solutions to streamline the procurement process and ensure that goods and services are procured from reliable vendors. This will ensure that the goods and services are procured from trusted suppliers and meet the quality standards.

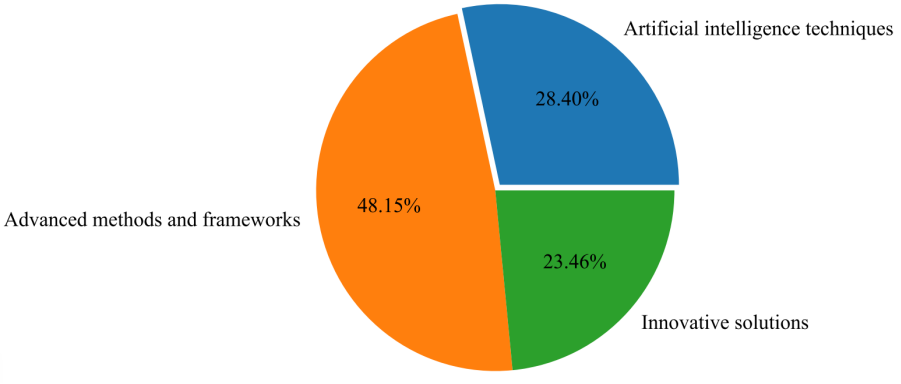
d Establishing an integrated logistics network to ensure that goods and services are delivered efficiently and to the right people. This will reduce the risk of goods being stolen or diverted to unintended recipients.

e Strengthening the collaboration between governments, NGOs, and private sector entities to ensure that goods and services are delivered in a timely and cost-effective manner. This will also help to reduce operational costs and ensure that goods reach the intended recipients on time.

4 Scope for future research

Given the setting of a pandemic, the topic of HSC frameworks provides a multitude of options for the conduct of further study. This evaluation calls attention to a number of possible topics that need additional examination. In the first place, there is the possibility of investigating how new technologies like blockchain, AI, and IoT may be incorporated into HSCs. It would be helpful to have an understanding of how these technologies might improve the level of transparency, traceability, and efficiency in the distribution of assistance during pandemics. Second, there is a need to pay attention to the role that data analytics and predictive modelling play in the process of optimising HSC operations. Increasing the number of models that can forecast demand, locate places that are susceptible, and maximise resource allocation would be beneficial to both preparation and response activities. Thirdly, there is a need for research into the evaluation of the social and cultural components of HSCs. This is an area that should be explored. When we get a better understanding of the ways in which cultural norms, social structures, and community participation influence the efficacy of supply chain interventions, we may develop strategies that are more situationally appropriate and culturally sensitive. In the fourth place, it is essential to conduct an analysis of the resilience and risk management measures used in HSCs. It would be beneficial to the entire response to investigate how supply networks can swiftly adapt and recover from disruptions caused by pandemics and to propose methods to reduce hazards. Last but not the least, investigating the function of public-private partnerships in HSCs during pandemics may provide useful information on the most efficient methods of collaboration and resource mobilisation. In conclusion, the potential for future research in the area of HSC frameworks in the context of a pandemic is enormous. There are possibilities ranging from the integration of technology to the study of social dynamics and risk management. Additional research in these areas may help in the construction of supply networks that are more durable and efficient, allowing for more effective responses to future crises. Figure 5 shows percentage contribution of literature related to various solution techniques for humanitarian SCM. It is observed from the figure that maximum number of papers are based on using advanced methods and frameworks. From the literature review, it is observed that there is increase in interest of using AI techniques in SCM.

Figure 5 Percentage contribution of literature related to damage detection techniques (see online version for colours)



Several studies have outlined following points:

1 The top five obstacles to implementing advanced digitalisation technology in developing nations like India are high implementation costs, a lack of financial resources, inadequate internet access, and IT infrastructure. Managers and academics can benefit from the findings' knowledge regarding pandemic-related digitalisation hurdles (Gupta et al., 2022). The term 'supply chain robustness' refers to a proactive approach to managing turbulence, change, or interruption. SCs are impacted by disruptions like the COVID-19 epidemic, severe transportation bottlenecks, and warfare conditions. The top issues on the agenda for corporate managers are inquiries about how to increase the supply chain's robustness (Alvim et al., 2022).

2 The COVID-19 has become one of the worst and most important health catastrophes in recent memory. The study contends that the frameworks for risk management in use today are insufficient for tackling transboundary threats. Therefore, risk assessments must take into account the newest and most recent risks (Prabhakar et al., 2021).

3 The next big step could be finding new ways for all nations to work together to prepare for pandemics. A viable approach necessitates global consensus among leaders, precise information sharing, and ongoing large-scale testing in contrast to focused isolations (Dey et al., 2020).

4 Managers may need to think about making disruptive adjustments to their companies due to disruptive environmental developments. A pandemic can also offer chances to start new relationships. Other vendors and partners might be more suited to assist the business in addressing its short-term needs and seizing long-term prospects (Obal and Gao, 2020).

5 Several efforts have been created in reaction to the COVID-19 pandemic to strengthen and modify the international framework for pandemic preparedness and response. The essential significance of universal health coverage in effectively and sustainably containing outbreaks has not received enough attention. The international community should not make the same mistakes in future health security initiatives that led to the pandemic's rapid spread in this year (Lal et al., 2022).

6 The COVID-19 pandemic can be prevented and controlled in part via the anti-epidemic SCs. As a major influencing factor, uncertainty has a significant impact on the SCs. Only a few studies have specifically looked into how technology innovation affects the SCs (Song et al., 2022). In the health-care supply chains (HCSC) literature, research on collaborative planning, forecasting, and replenishing techniques is lacking. Attempts to increase resilience are undermined by a fragmented deployment of existing SC collaborative risk management capabilities. There is a need for greater research that bridges the domains of humanitarian logistics, SC, and HCSC due to the dearth of HCSC publications in these journals (Friday et al., 2021).

Future research in the HSC Framework in the Context of Pandemic should focus on several key areas as follows:

1 *Optimising supply chain efficiencies*: The current HSC is often inefficient due to the lack of visibility, coordination, and collaboration between different stakeholders. Research should be conducted to better understand the current supply chain dynamics and develop strategies to improve efficiency.

2 *Improving data collection and analysis*: Data collection and analysis is a key component of understanding the needs of various stakeholders in the supply chain. Research should be conducted to better understand how data can be collected from different stakeholders and what methods can be used to analyse the data.

3 *Developing better risk management strategies*: Risk management is an essential component of the HSC. Research should be conducted to develop better strategies to identify, mitigate, and manage risks in the supply chain.

4 *Enhancing resilience and adaptability*: The HSC must be adapted to changing circumstances, such as the current pandemic. Research should be conducted to explore how to enhance the resilience and adaptability of the supply chain in order to better meet the needs of various stakeholders.

5 *Integrating technology*: Technology can be a powerful tool in improving the HSC. Research should be conducted to explore how to integrate different technologies into the supply chain in order to improve visibility, coordination, and collaboration.

5 Conclusion

This review paper provides an extensive analysis of the literature on the HSC framework in the context of pandemics, with a particular focus on the COVID-19 pandemic. The study critically examines over 150 papers published between 1992 and 2024, identifying important themes and opportunities for future research. The significant findings and their implications are summarised below:

1 The review highlights the necessity of integrating resilience and sustainability in HSCs, which have traditionally been studied separately. Thus, the study proposes a more robust framework that can better withstand and recover from disruptions by combining these two critical aspects. This integrated approach is essential for building supply chains that are both durable and capable of long-term sustainability.

2 The study emphasises the role of digitalisation and advanced technologies, such as data analytics, blockchain, and AI, in enhancing the efficiency and effectiveness of HSCs. Technological innovations can significantly improve the coordination, transparency, and responsiveness of supply chains, addressing many of the challenges observed during the COVID-19 pandemic. This finding encourages further research and investment in technological solutions within the humanitarian logistics domain.

3 Effective coordination between local networks and global actors is identified as a crucial factor in the success of HSCs. This balanced perspective ensures that the unique challenges and strengths at different levels of operation are addressed. Improved local-global coordination can lead to more efficient resource allocation and timely aid delivery during disasters.

4 The review also provides actionable insights and practical policy suggestions for organisations involved in humanitarian logistics. These recommendations can directly influence practice and implementation, helping organisations to develop more resilient and adaptive supply chains. Policymakers and practitioners can use these strategies to enhance their preparedness and response to future pandemics and other large-scale disasters.

5 The study identifies several gaps in the existing literature, including the need for more research on the integration of technological solutions and the importance of local-global coordination. Thus, this review helps guide subsequent studies in addressing these critical areas by outlining clear directions for future research. This targeted approach can accelerate advancements in the field and lead to more effective HSCs.

6 The review addresses the unique challenges posed by the COVID-19 pandemic, such as supply shortages and disruptions in logistics. Understanding these challenges provides valuable insights into how supply chains can be better prepared for similar global health crises in the future. This finding underscores the importance of developing adaptive and resilient supply chain strategies tailored to the specific context of pandemics.

7 Future work should explore the implementation and scalability of advanced technological solutions, such as machine learning and blockchain, in HSCs. Research should focus on how these technologies can be integrated into existing frameworks to enhance efficiency and transparency. There is a need for more research on data-driven decision-making processes in humanitarian logistics. Future studies should investigate how real-time data analytics can be used to predict and respond to disruptions more effectively. Given the complexity of HSCs, future research should adopt interdisciplinary approaches that combine insights from logistics, IT, public health, and social sciences. Such approaches can provide a more comprehensive understanding of the challenges and potential solutions. Developing standardised metrics for assessing resilience and sustainability in HSCs is crucial. Future research should aim to create and validate such metrics, enabling more consistent and comparable evaluations across different contexts. There is a need for more detailed studies on the role of policy and governance in HSCs. Research should focus on how different governance models can enhance coordination and resource allocation during crises.

Therefore, the comprehensive review conducted in this study significantly advances the understanding of HSCs during pandemics. This paper offers a robust framework for improving the resilience and sustainability of HSCs by synthesising insights from recent literature and identifying key areas for future research. The findings and recommendations provided here will serve as a valuable resource for researchers, policymakers, and practitioners in the field of humanitarian logistics and SCM. These contributions ensure that vulnerable populations receive timely and effective aid in future pandemics and other large-scale disasters, ultimately enhancing global disaster preparedness and response.

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