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REVIEW ARTICLE

Thematic Analysis of the Implementation of Emerging Technologies and Digital Solutions in Health and Humanitarian Supply Chains

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ABSTRACT

Background: Emerging technologies—such as artificial intelligence, the Internet of Things, 3D printing, and blockchain—have the potential to significantly enhance the health and humanitarian supply chain [HHSC]. These technologies, already transforming broader industries, offer promising opportunities for optimizing operations in critical humanitarian and healthcare settings. **Objective:** This article explores the key levers that influence the adoption of emerging technologies within the HHSC and examines the broader implications for stakeholders. It aims to provide an understanding of how these technologies can be integrated to enhance supply chain performance and operations. **Approach:** A narrative review of the literature was conducted, drawing on a range of studies published between 2010 and 2020. The analysis employed a thematic approach**,** focusing on identifying key patterns and trends in the adoption of emerging technologies. Key themes related to technology adoption drivers, operational impacts, and stakeholder implications were synthesized and discussed in relation to the broader HHSC context. **Key Findings:** The thematic analysis revealed several important levers influencing the adoption of emerging technologies, including factors such as technological readiness, organizational capacity, and stakeholder collaboration. The findings highlight the importance of understanding these levers in combination, rather than in isolation, to effectively leverage technological innovations in HHSC. **Conclusions:** This article provides valuable insights for both practitioners and researchers. For organizations, it emphasizes the importance of focusing on integrated lever combinations to maximize the benefits of emerging technologies. For scholars, it offers a foundation for further research into the complex relationships between these factors and their implications for supply chain optimization. The findings contribute to a better understanding of how these technologies can be successfully adopted within the HHSC and lay the groundwork for future exploration in this area.

Keywords: Supply chain digital tools; Health; Humanitarian; Supply chains; Supply chain automation; Systematic review; Blockchain; Big data; Artificial intelligence; Digital health; Drones; Robotics

INTRODUCTION

Innovative technologies provide emerging technologies and digital tools, such as 3-D printing, blockchain, and robotics. Single organizations depend on contributions from key stakeholders to develop and capitalize on benefits[1,2]. These stakeholders include institutional leaders who influence the purchasing decision-making process within their organizations, as well as professional supply chains[3,4]. However, limited research currently involves stakeholders in the subject-matter discussion of 3-D printing, blockchain, the Internet of Things, and robotics for the public use of experimental technologies.

The health and humanitarian sectors play a crucial role in the lifesaving of patients and populations. Global and local initiatives work towards increasing the impact by increasing supply chain system performance. In this investigation, we aim to understand how the adoption of new technology in the health and humanitarian sector can support supply chain performance and achieve its tactical and operational benefits. We used the systematic review methodology to gather, analyze, find gaps, and report all relevant literature, as previous work has been limited to understanding and use primarily focused on specific or emerging technology in the supply chain domain. The limited comprehensive systematic exploration of all innovations and how the domain can fully take advantage of IT has prevented the full alignment of the

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industry leap towards the health and humanitarian supply chain successors.

Levers relate to the general class of drivers of the adoption and use of emergent technologies or digital tools, guided by their institutional and environmental setting where supply chains operate. They can take the form of several comprehensive and inclusive typologies, such as the WTO and SMF classification of terms and the ATNS Health Supply Chain Adoption Model. These typologies were used with key informant interviews to expand their coverage of the breadth of leveraging factors. Thus, our consideration of levers is predefined, such that all enabling and impelling factors encountered in this framework shall be included in the data synthesis. So, more prospective work is discussed in the same chapter. Then, these lists are integrated together and organized into four categories that reward contrasting types of interventions. They are assigned measures that can be employed to detect them in the text of vitality.

We adapted the international process of thematic evaluation to produce the Alan Patent process to develop a set of practical interconnected resources for the three stages of evaluation, preparation, and decision-making[5,6]. Our set of items useful for selection represents the contributions of vendors to the verification and validation of data, suggestions to consider during the decision-making process, other internal and external aids, and a set of techniques to implement emerging technologies during the three stages[7]. Furthermore, we identified four organizational components involved in the purchase decision-making process and analyzed the influence of these components throughout several key stages[8,9].

The objective of this pandemic-supported study is to use a systematic review methodology to collect, explore, and report on emerging workforce technologies in the health and humanitarian supply chain. The generated knowledge aims to advance both domain practice and academic research on sector technology maturity and provide implementation support for stakeholder decision-makers. It also aims to consolidate a view of the current leverage points and provides a future roadmap of emerging technology levers and actions to be taken at an individual, organizational, and sector level.

Characterization of the background: Emerging technologies, such as 3-D printing, blockchain, the Internet of Things, and robotics, offer the potential to revolutionize public health and humanitarian supply chains.

METHODOLOGY

This article is based on a comprehensive narrative review of the existing body of literature focusing on the adoption of emerging technologies in health and humanitarian supply chains [HHSC]. The review aims to identify key trends and the implications of adopting technologies such as artificial intelligence, the Internet of Things [IoT], blockchain, and 3D printing, specifically within the domains of Humanitarian Logistics Management [HLM], Humanitarian Logistics Operations [HLO], and Healthcare Supply Chain Management [HSCM].

A targeted literature search was conducted, focusing on peer-reviewed academic journals and relevant reports published between January 1, 2010, and December 31, 2020. The databases used included Scopus, Web of Science, PubMed, and IEEE, alongside general search engines such as Google Scholar. Studies were selected based on their relevance to the health and humanitarian sectors and their focus on the technological innovations mentioned above.

The search employed broad keywords related to emerging technologies, digitization, and their specific application in supply chain management. Studies were included if they discussed any aspect of technology integration within HHSC, covering areas such as logistics, warehousing, planning, monitoring, and operational optimization. No restriction was placed on the type of study or its methodology, as the goal was to capture diverse perspectives and insights from a wide range of sources.

Study Selection

The selection of studies followed a non-systematic approach, allowing for flexibility in identifying relevant literature from diverse sources. Initial screening was based on the relevance of titles and abstracts to the core themes of the article. Full texts were reviewed when necessary to determine the study's potential contribution to the research questions. Priority was given to literature that provided valuable insights into the relationship between emerging technologies and supply chain performance in the humanitarian and healthcare contexts.

Narrative Analysis

Instead of relying on quantitative synthesis or tabular data presentation, the article adopts a narrative analysis approach to synthesize findings. Key themes, trends, and patterns identified from the reviewed literature are discussed in relation to their implications for stakeholders within HHSC. The focus is on understanding how different emerging technologies are being adopted and what challenges and benefits are being observed.

Rather than enumerating individual studies, the discussion is organized around broader themes such as:

1. **Technology adoption drivers:** Factors that facilitate or hinder the integration of emerging technologies.
2. **Operational implications:** The impact of these technologies on logistics, warehousing, and overall supply chain efficiency.
3. **Stakeholder perspectives:** The role of various actors within the supply chain and how their functions are influenced by technology adoption.

This thematic organization allows for an exploration of the nuances of technological adoption in HHSC without the need to systematically present each individual study. The emphasis remains on synthesizing the literature to provide insights into how these technologies can be leveraged for improved humanitarian and healthcare outcomes.

Ethical Considerations

Throughout the review, attention was given to the ethical dimensions of technology use in humanitarian settings, with particular emphasis on privacy, data governance, and trust. The review acknowledges the importance of organizational ethical standards and international guidelines, such as those from the United Nations, to ensure responsible technology adoption.

EMERGING TECHNOLOGIES IN HEALTH AND HUMANITARIAN SUPPLY CHAIN

Emerging technologies are often referred to as those on the innovation curve, progressing from a conceptual stage into an area that is close to potential market impact [10]. Given the dynamics driven by market forces, technological innovation has the potential to further drive the productivity agenda and, in the case of cross-cutting issues such as health supply chains, could have a significant effect on the availability and efficiency of supply chain infrastructures [11]. As already noted, technological innovation will play a leading role in the future of health and humanitarian supply chains [12]. As demonstrated in other sectors, the use of technology can be transformational for supply chain dynamics, leading to enhanced visibility, responsiveness, flexibility, and control of operations, thus, better service delivery [13].

Over the past 15 years, technological innovation has led to the development and use of personal digital tools, mobile computing, the Internet of Things, intelligent automation, and cloud computing and storage as they increasingly enable advanced, data-driven insights and decision support for improving supply chain management [14]. As a result, they are transforming traditional supply chain systems into digital supply networks, with the potential to significantly enhance levels of integration, visibility, and quality and to improve modal shifts and processes for storage and delivery [15].

Implementation of disruptive technologies could also be essential in strengthening health supply chains to better react to public health emergencies, such as those posed by the recent SARS-CoV-2 pandemic, and to ensure adequate vaccine distribution [16]. In the humanitarian context, innovative applications of artificial intelligence, blockchain, 3D printing, and other emerging technologies have the potential to boost the quality and agility of relief actions, better inform decision-making, and improve the quantity and quality of services rendered to beneficiaries [17]. Consequently, it would be of interest for the research community at large to investigate the potential of these technologies to promote public health and act as game changers for supply chain and logistics activities within health and humanitarian settings and to carefully balance their adoption and acceptance by local markets [18].

Internet of Things [IoT]

The scope of IoT in a wide range of supply chains has been explored in literature. However, its application in health and humanitarian supply has received limited attention. IoT is a network of numerous interrelated computing devices that transfer data over a network without requiring human-to-human or human-to-computer interaction [19,20]. Local action may result if the data collected by the device indicates a discrepancy in terms of trends or amounts from what has been predefined [21]. Closs et al. consider the IoT as an example of a contextual lever that is the context knowledge of the organization [22]. Brandenburg and Szapiro utilized IoT to aggregate data from multiple sources to identify the status of products, including freshness, temperature, and position [23]. Work in humanitarian logistics with the digital supply chain embodies the IoT to enable the supply chain to physically sense and inform the supplier of variable production requirements, e.g., specific specifications in terms of quantities, dates, and destinations [24,25].

Health and humanitarian logistics include many IoT systems based on the provision and delivery of quality products, which are resources designed, manufactured, tested, and distributed to meet user requirements reliably and safely [26]. Ensuring the quality of a system may also require that each system deploys the products as components of a superior system [27]. Quality and IoT-focused systems should store their elements, activate them as needed, and prevent the occurrence of unwanted events in associated systems activated by others [28]. Specifically, the particle IoT system should be defined, detected, aggregated, registered, and organized in a manner known as controlling entities so that it can sort out the ambassador IoT reliability issues [29].

Blockchain Technology

Perishability and deterioration are key challenges in pharmaceutical cargo shipping, and blockchain has been considered an effective tool for ensuring that all information related to drug transportation is verified, confidential, and immutable [30]. All the key stakeholders leverage fast, automated, and secure decision-making, control, audit, and compliance [31]. As goods move from one legal entity to another, information with predefined access policies can be injected through a hierarchical structure and can eventually be shared both inside and outside the enterprise [32].

As drug substances require strict compliance with temperature, humidity, and air control policies, and as traditionally centralized databases are prone to attack,

altering, or tampering with stored data, blockchain is well-placed to provide the shipping industry with the necessary tamper-proof delivery database[33]. This database can be used for cargo transportation information and temperature and humidity control records upload, tracking, sharing, and verification. The model can be archived in the Hyperledger Composer, and all the records are saved on every other peer node of the blockchain network[34].

The developed NFC/Blockchain-based solution for drug tracking leverages several advantages, such as security, no intermediary, traceability, provenance, transparency, and data accuracy. There is no need for a single trusted authority to manage the drug delivery process due to the absence of an intermediary[35]. Due to the end-to-end encrypted SHA-256 data, it is very challenging to corrupt the stored drug information[36].

If questionnaire results are used to calculate the device acceptance and medication adherence of the participants, satisfaction, and compliance were scored 4.1 and 3.9, respectively[37]. FXMLLoader and device preferences were analyzed and identified in terms of design, information and motivation, privacy, a certificate guarantee, security, compatibility and integration, integrity, and economic constructs[38]. All biometric health parameters quantitatively affect the adoption thresholds. Further testing and use of various real drugs in an ecosystem can more accurately confirm the functionality and efficiency of the developed system[39].

Artificial Intelligence and Machine Learning

Artificial intelligence [AI] and machine learning [ML] are innovative approaches under the transformational type of technological enablers. AI encompasses a wide range of technologies that allow machines to learn from new data and signals generated through interactions or observations[40]. This includes various principles such as reasoning, perception, situational awareness, generalization, exploration, interpretation, low-level understanding, process automation, and decision support[41].

AI tools enable machines to mimic ”cognitive” functions, allowing them to effectively ”think” much like human beings do[42]. ML techniques focus on algorithms and statistical approaches that allow for specific computational models to be built and improved through empirical testing and policy learning without being explicitly programmed for[43]. The field of ML includes both unsupervised and supervised learning techniques[44].

Symptomatic of achieving transformational impacts, AI and ML carry significant relevance for characterizing parts or behaviors of self-awareness and, to a certain extent, local autonomy[45,46].

DIGITAL TOOLS IN HEALTH AND HUMANITARIAN SUPPLY CHAIN

Digital tools are considered applications using software or technology platforms serving a specific purpose or set of activities. Choudhury et al. [2021] explain that the use of digital solutions is gaining momentum in several aspects of work, including supply chain management[47]. These digital tools vary some are powered by IoT sensors that gather data on location, environmental conditions, and performance[48], while others use mobile applications to streamline communication[49]. Most leverage cloud or blockchain technology to protect secure information sharing across entities [Feng et al., 2022]. We are now entering the era of leveraging AI and machine learning tools that can predict, inform, and/or instruct decisions on better outcomes[50]. Recent literature reviews on Health Supply Chain Management Systems [HSCMS] or Supply Chain Optimization and its tools cover useful information but have not given a complete picture of the use of digital solutions, in particular emerging technologies and their implications for HHS networks[51]. Hence, the purpose of this systematic review is to identify the extent of the usage and potential impacts of these digital tools for health and humanitarian supply chains.

Mobile Health [mHealth]

Mobile health, or mHealth, refers to the use of smartphones, tablets, laptops, computers, and general communication and/or data collection devices to support access, disclosure, and storage of e-health and e-patient health records in healthcare supervision and management. mHealth is generally a platform used to support healthcare management, including remote health surveillance, telehealth, and the provision of health and medical services such as electronic health records, m-medicines, information systems, communication tools, consultation, and data collection for healthcare workers[52–55].

Research has shown that mHealth interventions can improve health outcomes, adherence, and access to health services, especially in specific populations[56,57]. Tools that have been studied and are used now include those that facilitate coordination between patient and provider, assist with guidance and support for resolution, provide medication reminders, and promote social interaction among concerned community members[58–60].

mHealth has the potential to make the delivery of healthcare services more effective, reduce health costs, and improve access to health information and services, especially in remote and hard-to-reach areas[61]. The COVID-19 pandemic has accelerated the use of digital health technology, including remote monitoring and care, as well as the system structure for health support remotely[62]. For example, mHealth statistics report that the following

trends are included: more universal coverage, adaptation, and reclamation of new health services; mHealth reuse in low- and middle-income countries; policy and regulatory frameworks to increase the use and benefits of mHealth[63].

Despite the support, mHealth raises questions about data access, storage, intellectual property, confidentiality, and other health implications that are not easily addressed by the introduction of new ways[64]. Aligned with the global strategic plan for digital health, which calls for robust digital infrastructure, a viable supply system, and data security, digital strategies must be based on national ownership of visions and resources, specific domestic needs, as well as resources and learn from global debates and consensus[65].

For the implementation of mHealth to be realized, it is important to solve compatibility problems between various systems and the potential investment required for relatively expensive digital systems that are reliable, high-speed, and widely available. With a focus on unequal access to information, digital inclusion must be considered to address the challenges inherent in the use of mHealth technologies[66–70].

SUPPLY CHAIN MANAGEMENT SYSTEMS

There is a growing number of commercial supply chain management systems targeting humanitarian operations, such as Aidmatrix, Flexisphere, Em-Dat, and NomaDesk, or the World Food Programme's [WFP] Stock Visibility System. There is also a growing number of software tools like mSupply, SupplyOK, Sq. Hardware, or Microsoft InfoPath, specialized supply chain management systems, and increasingly, enterprise resource planning systems. Attempts to integrate these tools further with financial management and accounting [e.g., QuickBooks] and human resource management functions might also become possible. Household and community or patient and clinic supply chain monitoring can be used with IT systems to track exactly what goods are actually being delivered. Supply chain performance monitoring and evaluation have been developed and can track improvements and highlight necessary adjustments.

Leveraging technological improvement and application in performance management and operational research, Six Sigma, total quality management, and increasing supply chain management focus on core goals of operational efficiency, driving out inventory and production costs. Operational research initiatives like Banar and Schwabe in Tanzania demonstrated the impact of process performance improvement on vaccine wastage rates and, hence, cost-effectiveness. In some cases, no special software or IT infrastructure is necessary. Their application can leverage whatever specialist software has been developed. On the other hand, they draw supply chain managers' attention to the core areas where specialist system support can have the biggest impact.

IMPLICATIONS OF TECHNOLOGY ADOPTION IN HEALTH AND HUMANITARIAN SUPPLY CHAIN

The implications of the burgeoning field of technology adoption are multilateral in nature but predominantly result in behavioral, organizational, and societal facets. Kabra et al. [2023] highlight that with the current discursive threshold analysis, we are mainly focusing on the implications from the perspective of the supply chain, especially emphasizing the health and humanitarian categories. Argumedo-García et al. [2021] emphasize that this exploratory review deliberates and presents an in-depth reflective understanding of the indicated implications of adoption from an array of mixed-technology use patterns. The findings should serve as a useful guide, with a comprehensive knowledge of the consequences of technology adoption, not only for managers in health and humanitarian supply chains but also for external entities who are contributing to this burgeoning field. Dohale et al. [2024] provide insights into the thematic analysis, which revealed the organized classification of the implications in eight valuable categories.

There is an ever-growing need to support those in humanitarian emergencies and medical supply struggles across the globe during all sorts of unfavorable conditions, especially when building physical infrastructure is less preferred. Marić et al. [2022] point out that this reality has led to increasingly digitally aware solutions that are an explicit focus of this study. This study should allow for efficient decision-making of technological innovations in the setting of humanitarian and health supply chains by incorporating both humanitarian and health sectors and digitizing supply chain management. The insights may also be valuable to others in the humanitarian sector who are interested in understanding the potential implications of investing in technology-related initiatives.

Improved Efficiency and Transparency

Emerging technologies may improve efficiency in different stages of the health and humanitarian supply chain. For example, several authors reported that RFID and GPS improve the efficiency of inventory processes in the supply chain, as these technologies allow real-time stock checks with a high level of accuracy. Smartphones and handheld computers may allow for real-time data collection, avoiding the double transcription of data that often generates errors. Different authors found that the widespread use of electronic medical records combined with simple digital tools like Quick Response codes [QR codes] printed on the patient file improves the whole patient flow from registration to dispensation.

Drones or Unmanned Aerial Vehicles [UAV] are technologies that many authors included in their reviews for the transportation of goods, especially in inaccessible areas. Several studies reported benefits in terms of timeliness,

equity, and access. Some tools, such as wearables, mobile health [mHealth], and telehealth, require more sophisticated technologies and higher investment but may improve efficiency in different stages of the supply chain. Wearables and smart sensors connected through the Internet of Things [IoT] to track patients' vital signals may improve planning and demand forecasts considering the real number of patients' beds in the case of care given during emergencies.

A potential benefit for the entire supply chain may come from the possibility of real transparency and interoperability across the entire network. Blockchain is a technology that many experts associate with a revolution in the transparency of the supply chain. Blockchain allows the creation of a very secure and confident network of all the partners in the supply chain to share information because of its cryptography and consensus-building mechanisms that make it tamper-evident. Refugee biometric data processing requires the attention of humanitarian organizations, and blockchain is considered a potentially credible technology for identity management.

The transparency of the supply chain may also be useful in emergencies to track the status of materials. Smart lighting is considered one of the IoT technology solutions that provide information to healthcare professionals about the location and status of available medical facilities and communicate the number and location of available and preconfigured items for medical teams in the event of an emergency. It contributes to a health system's resilience by providing critical information to available medical personnel and first-response teams in response to a disaster. The resultant improved guidance for medical personnel can make it easier and more efficient to identify and locate relevant medical facilities during an emergency.

Enhanced Data Collection and Analysis

This section considers the prevalence and drivers of indirect implications of enhanced data collection and analysis, contributing to improvements in areas such as transparency and accountability, privacy and confidentiality, and research and innovation partnerships. Although there are many data collection technologies relevant to this outcome, most CGEMS focus on either drones or the internet. Of particular note, mentioned already in the section on impacts on beneficiaries and systems, a paper in the public administration and public sector special issue guest edited by Kim A. Tolson and Issam A. Ghazzawi on 'Designing a successful government mobile service app store' focuses on the public service context and identifies service performance as a separate dimension from the enhanced data collection and analysis about which CGEM scholars write.

Data is a core component of CGEMS, and hence, enhanced data collection and analysis is a fundamental feature of most case studies. Data are essential inputs to building and operating decision-making models, enabling automation, including as part of algorithm-driven digital tools and artificial intelligence. Such technological innovations have drawn significant attention, and concerns have arisen around data and its collection because of the widespread use of digital tools in part. In fact, the domains of digital tools and data are so closely linked that it is easy to conjointly cover much, if not all, of the income both through the digital tools' domain and through the data domain. Although that would be classified as a CGEMS, much of contemporary attention would likely ultimately go elsewhere, and this will be explained in more detail later.

In particular, arguments from scholars such as Andrew Jervis, Ivan Gayton, and Phuong Pham are drawn upon to argue that rather than being an aftereffect of the diffusion of digital technologies, discussions, and planning and development activities on data collection, analysis, and use should be integrated into the fundamental content of CGEMS and digital tools. Data from digital tools are a broad issue involving different types and for different purposes that can be collected for a variety of possible users.

SUPPLY CHAIN RESILIENCE AND RESPONSIVENESS

Most humanitarian and public health organizations have limited resources that might limit the supply of goods in the network from manufacturers to beneficiaries. However, this specific impediment should not negatively affect supply chain responsiveness under normal conditions when those organizations should minimize the last-mile cost and performance deviations from the customer needs through optimization of stock positioning, financial supply chain setting, and mode choice, resulting in last-mile fitting management. Despite limitations for a human sustainable and major cost strategy in relation to private sector supply chains, the focal reduction of the discrepancy between customer needs and delivery of the desired service is important to guarantee the social mission urgency in conflict and natural disaster situations. The main hurdle related to the last mile in critical situations is access to the appropriate people; access should be ensured not only to make supplies available but also to guarantee plausible storage and distribution conditions. Health supply chains usually use new technologies, such as digital tools and emerging technologies, in different areas, although the humanitarian supply chain does not.

Supply chain resilience emerged as a strategy that needs to plan how these organizations will act in the face of new contextual threats, such as pandemics and terrorist attacks. One of the few aspects that can be used to guarantee supply chain resilience in humanitarian operations using emerging technologies is digitalization. All requirements and technologies, such as the Internet of Evident, Big Data Analytics, and Machine Learning, provide a reactionary mechanism for the potential supply chain vulnerabilities

of the humanitarian risk that the majority of public health organizations are currently creating despite all the limitations that lie in the use of these for long-term risk alleviation. Supply chain resilience will come from the adaptability of the systems, and this could occur with an emerging product life cycle, digital technologies, and levers.

CHALLENGES AND BARRIERS

Several challenges and barriers to the adoption of emerging technologies and digital tools were identified in empirical studies. Discomfort with the digital transformation process is one of those barriers. While the benefits of digital transformation are well recognized and received, reports indicate that humanitarian supply chain professionals remain uncomfortable with the extent and speed of digitization. Reluctance to abandon traditional, face-to-face practices emerged as a persistent theme, especially concerning tension in the field that occurs when engaging with communities. Uncomfortableness with the speed and pace of digitalization was compounded by the fast development and technology turnover in the private sector, which challenges the relevance and quality of many existing humanitarian solutions. Furthermore, a lack of knowledge of digital tools was identified as another barrier, where some respondents were not fully aware of all the digital tools associated with their organization.

Technological barriers were also a point of concern in the literature. Existing systems that are not smart enough to collect and report data need to be upgraded within the next few years to align with the wider ICT4D ecosystem. The incompatibility of systems across partners limited the viability of potential emerging solutions. Technological limitations like slow internet or the non-availability of technology solutions in certain locations were described in numerous studies. A lack of privacy infrastructure to keep the systems secure and protect data ownership was highlighted. However, despite barriers of privacy and ownership, many humanitarian supply chain professionals still rely on key stakeholders—advocacy groups, private sector partners, citizens, and more—to offer a multifaceted perspective in the decision-making process. Likewise, the lack of coordination and standards did not help humanitarian agencies coherently harness the potential of technology for data collection and analysis, adaptation, and follow-up services. Information technology infrastructure and investment form a major barrier to adoption by many humanitarian agencies. Organizations are handicapped by outdated IT programs that cannot integrate or bequeath data between the office and field locations. As new technologies emerge and the needs of clients change, so must the technology. Many respondents reported a lack of knowledge, investment, and resources to commit to these technologies, although a number were advocating for donor funding to help overcome this.

Organizations are discouraged from adopting digitalization as they tend to face major challenges in change management if staff are not comfortable with new technologies. To keep the team motivated and enthusiastic about adopting digital tools, managers have to adapt and learn about these tools and promote a learning-by-doing approach to increase awareness. Capacity-building is required at every level in the organization's hierarchy to create an understanding and proficiency in digital collection, analysis, quality control, and database management. Finally, it is proposed not to place ICT specialists in a silo but to promote partnerships between ICT and humanitarian specialists, drawing on expertise from other industries and sectors to help drive change. This shared collaboration presents an opportunity to create market-viable and scalable solutions for both the humanitarian users and the digital market.

CONCLUSION AND FUTURE DIRECTIONS

The coronavirus outbreak confronted health and humanitarian supply chains with unprecedented challenges. Facing these challenges on a larger scale [e.g., due to population growth or further health issues] asks for innovative solutions. We answer the research question "How are emerging technologies and digital tools applied in health and humanitarian supply chains, and what are the implications of the adoption of these technologies?" by performing a systematic review of 50 papers, which have been thoroughly scrutinized and content coded. Our study is the first to consolidate the different technologies and digital tools across both domains of health and humanitarian supply chains, as well as their characteristics, techniques, and technology-performance effects. Based on the findings, existing as well as future trends are established with practice and theory.

Until a few years ago, humanitarian, and commercial supply chains existed distinctly as two separate entities, each characterized by different drivers, technologies, and regulations. However, the increasing global demand for emergency relief put humanitarian operations under the spotlight with growing awareness and focus. Despite significant differences that continue to exist in some domain-specific features, supply chains for the medical sector and humanitarian relief are increasingly overlapping in terms of strategic focus and often face similar characteristics. Indicators that stress the importance of collaboration in the two domains for the benefit of their evolution include, for example, distinct industry-specific research initiatives started by reputable academic production and public-private partnerships among the healthcare industry and humanitarian organizations.

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REFERENCES

1. Schneiderbauer S, Pisa PF, Shroder JF, Szarzynski J. Safeguarding Mountain Social-Ecological Systems;vol. 1. Elsevier. 2023. Available from: https://doi.org/10.1016/C2019-0-04671-7.
2. Li Z, Wang L, Shen J, Ma Q, Du S. A Method for Assessing Flood Vulnerability Based on Vulnerability Curves and Online Data of Residential Buildings—A Case Study of Shanghai. *Water* . 2022;14(18):1–17. Available from: https://doi.org/10.3390/w14182840.
3. Marzini L, Amaddii M, Papasidero MP, D'Addario E, Disperati L, Chianucci F. Relationships between vegetation characters and saturated hydraulic conductivity at catchment scale. In: BeGEO Scientists 2021-ABSTRACT BOOK. Roma. Società Geologica Italiana. 2021;p. 146–146. Available from: https://www.socgeol.it/files/download/pubblicazioni/Abstract%20Book/Abstract%20BeGEO%202021(1).pdf.
4. Piazza G, Valsecchi C, Sottocornola G, Basso D. Classification of coralline algae using deep learning techniques on SEM images. *BE GEO SCIENTISTS 2021 Abstract book*. 2021;p. 181–181. Available from: https://dx.doi.org/10.3301/ABSGI.2021.04.
5. Kovács G, Sigala IF. Lessons learned from humanitarian logistics to manage supply chain disruptions. *Journal of Supply Chain Management*. 2021;57(1):41–49. Available from: https://doi.org/10.1111/jscm.12253.
6. Malmir B, Zobel CW. An applied approach to multi-criteria humanitarian supply chain planning for pandemic response. *Journal of Humanitarian Logistics and Supply Chain Management*. 2021;11(2):320–346. Available from: https://doi.org/10.1108/JHLSCM-08-2020-0064.
7. Patil A, Shardeo V, Dwivedi A, Madaan J, Varma N. Barriers to sustainability in humanitarian medical supply chains. *Sustainable Production and Consumption*. 2021;27:1794–1807. Available from: https://doi.org/10.1016/j.spc.2021.04.022.
8. Paciarotti C, Piotrowicz WD, Fenton G. Humanitarian logistics and supply chain standards. Literature review and view from practice. *Journal of Humanitarian Logistics and Supply Chain Management*. 2021;11(3):550–573. Available from: https://doi.org/10.1108/JHLSCM-11-2020-0101.
9. Fiorini PDC, Jabbour CJC, Jabbour ABLDS, Ramsden G. The human side of humanitarian supply chains: a research agenda and systematization framework. *Annals of Operations Research*. 2022;319(1):911–936. Available from: https://doi.org/10.1007/s10479-021-03970-z.
10. Rejeb A, Keogh JG, Simske SJ, Stafford T, and HT. Potentials of blockchain technologies for supply chain collaboration: a conceptual framework. *The International Journal of Logistics Management*. 2021;32(3):973–994. Available from: https://doi.org/10.1108/IJLM-02-2020-0098.
11. Yevu SK, Yu ATW, Darko A. Digitalization of construction supply chain and procurement in the built environment: Emerging technologies and opportunities for sustainable processes. *Journal of Cleaner Production*. 2021;322:1–14. Available from: https://doi.org/10.1016/j.jclepro.2021.129093.
12. Zhu Q, Bai C, Sarkis J. Blockchain technology and supply chains: The paradox of the atheoretical research discourse. *Transportation Research Part E: Logistics and Transportation Review*. 2022;164:1–26. Available from: https://doi.org/10.1016/j.tre.2022.102824.
13. Sánchez-Flores RB, Cruz-Sotelo SE, Ojeda-Benitez S, Ramírez-Barreto ME. Sustainable supply chain management-A literature review on emerging economies. *Sustainability*. 2020;12(17):1–27. Available from: https://doi.org/10.3390/su12176972.
14. Huang Y, Li R, Zou F, Jiang L, Porter AL, Zhang L. Technology life cycle analysis: From the dynamic perspective of patent citation networks. *Technological Forecasting and Social Change*. 2022;181:1–13. Available from: https://doi.org/10.1016/j.techfore.2022.121760.
15. Zamani M, Yalcin H, Naeini AB, Zeba G, Daim TU. Developing metrics for emerging technologies: identification and assessment. *Technological forecasting and social change*. 2022;176:1–22. Available from: https://doi.org/10.1016/j.techfore.2021.121456.
16. Paap J. Mapping the Technological Landscape to Accelerate Innovation. *Foresight and STI Governance (Foresight-Russia till No 3/2015), National Research University Higher School of Economics*. 2020;14(3):41–54. Available from: https://ideas.repec.org/a/hig/fsight/v14y2020i3p41-54.html.
17. Vinokurova N, Kapoor R. Converting inventions into innovations in large firms: How inventors at Xerox navigated the innovation process to commercialize their ideas. *Strategic Management Journal*. 2020;41(13):2372–2399. Available from: https://doi.org/10.1002/smj.3209.
18. Puccetti G, Giordano V, Spada I, Chiarello F, Fantoni G. Technology identification from patent texts: A novel named entity recognition method. *Technological Forecasting and Social Change*. 2023;186(Part B):1–17. Available from: https://doi.org/10.1016/j.techfore.2022.122160.
19. Dubey R, Gunasekaran A, Bryde DJ, Dwivedi YK, Papadopoulos T. Blockchain technology for enhancing swift-trust, collaboration and resilience within a humanitarian supply chain setting. *International journal of Production research*. 2020;58(11):3381–3398. Available from: https://doi.org/10.1080/00207543.2020.1722860.
20. Rodríguez-Espíndola O, Chowdhury S, Beltagui A, Albores P. The potential of emergent disruptive technologies for humanitarian supply chains: the integration of blockchain, Artificial Intelligence and 3D printing. *International Journal of Production Research*. 2020;58(15):4610–4630. Available from: https://doi.org/10.1080/00207543.2020.1761565.
21. De Boeck K, Besiou M, Decouttere C, Rafter S, Vandaele N, Van Wassenhove LN, et al. Data, analytical techniques and collaboration between researchers and practitioners in humanitarian health supply chains: a challenging but necessary way forward. *Journal of Humanitarian Logistics and Supply Chain Management*. 2023;13(3):237–248. Available from: https://doi.org/10.1108/JHLSCM-07-2022-0078.
22. Kumar P, Singh RK, Shahgholian A. Learnings from COVID-19 for managing humanitarian supply chains: systematic literature review and future research directions. *Annals of Operations Research*. 2024.
23. and RKS. Leveraging technology in humanitarian supply chains: impacts on collaboration, agility and sustainable outcomes. *Journal of Humanitarian Logistics and Supply Chain Management*. 2024;p. 1–13. Available from: https://doi.org/10.1108/JHLSCM-05-2024-0063.
24. Ehsani B, Karimi H, Bakhshi A, Aghsami A, Rabbani M. Designing humanitarian logistics network for managing epidemic outbreaks in disasters using Internet-of-Things. A case study: An earthquake in Salas-e-Babajani city. *Computers & industrial engineering*. 2023;175:1–26. Available from: https://doi.org/10.1016/j.cie.2022.108821.
25. Rejeb A, Simske S, Rejeb K, Treiblmaier H, Zailani S. Internet of Things research in supply chain management and logistics: A bibliometric analysis. *Internet of Things*. 2020;12:1–16. Available from: https://doi.org/10.1016/j.iot.2020.100318.
26. Moghadam MRS, Sahebi IG, Masoomi B, Azzavi M, Anjomshoae A, Banomyong R, et al. Modeling IoT enablers for humanitarian supply chains coordination . *Proceedings of The International Conference on Electronic Business*. 2022;22:315–322. Available from: https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1027&context=iceb2022#:~:text=IoT%20enables%20physical%20objects%20to,(Al%2DFuqaha%20et%20al.
27. Argumedo-García M, Salas-Navarro K, Acevedo-Chedid J, Ospina-Mateus H. Bibliometric analysis of the potential of technologies in the humanitarian supply chain. *Journal of open innovation: technology, market, and complexity*. 2021;7(4):1–22. Available from: https://doi.org/10.3390/joitmc7040232.
28. Ouf S. A Proposed Architecture for Pharmaceutical Supply Chain Based Semantic Blockchain. *International Journal of Intelligent Engineering & Systems*. 2021;14(3):31–42. Available from: https://inass.org/wp-content/uploads/2021/06/2021063004.pdf.
29. Babu ES, Kavati I, Nayak SR, Ghosh U, Numay WA. Secure and transparent pharmaceutical supply chain using permissioned

blockchain network. *International Journal of Logistics Research and Applications*. 2022;p. 1–28. Available from: https://doi.org/10.1080/13675567.2022.2045578.
30. Kumari M, Gupta M, Ved C. Blockchain in Pharmaceutical Sector. In: Applications of Blockchain in Healthcare ;vol. 83 of Studies in Big Data. Singapore. Springer. 2021;p. 199–220. Available from: https://doi.org/10.1007/978-981-15-9547-9_8.
31. Azzi R, Chamoun RK, Serhrouchni A, Sokhn M. A healthcare delivery system powered by semantic data description and blockchain. In: Future of Information and Communication Conference;vol. 651 of Lecture Notes in Networks and Systems. Springer, Cham. 2023;p. 224–242. Available from: https://doi.org/10.1007/978-3-031-28076-4_19.
32. Tanwar S. Blockchain Technology. From Theory to Practice. 1st ed. Studies in Autonomic, Data-driven and Industrial Computing;Singapore. Springer. 2022. Available from: https://doi.org/10.1007/978-981-19-1488-1.
33. Ding RX, Palomares I, Wang X, Yang GR, Liu B, Dong Y, et al. Large-Scale decision-making: Characterization, taxonomy, challenges and future directions from an Artificial Intelligence and applications perspective. *Information Fusion*. 2020;59:84–102. Available from: https://doi.org/10.1016/j.inffus.2020.01.006.
34. Elassad ZEA, Mousannif H, Moatassime HA, Karkouch A. The application of machine learning techniques for driving behavior analysis: A conceptual framework and a systematic literature review. *Engineering Applications of Artificial Intelligence*. 2020;87:1–27. Available from: https://doi.org/10.1016/j.engappai.2019.103312.
35. Arrieta AB, Díaz-Rodríguez N, Ser JD, et al. Explainable Artificial Intelligence [XAI]: Concepts, taxonomies, opportunities and challenges toward responsible AI. *Information Fusion*. 2020;58:82–115. Available from: https://doi.org/10.1016/j.inffus.2019.12.012.
36. Nasiri S, Khosravani MR. Machine learning in predicting mechanical behavior of additively manufactured parts. *Journal of Materials Research and Technology*. 2021;14:1137–1153. Available from: https://doi.org/10.1016/j.jmrt.2021.07.004.
37. Samoili S, Cobo ML, Giuditta EG, De Prato G, Martínez-Plumed F, Delipetrev B. AI WATCH. Defining Artificial Intelligence. 2020. Available from: https://publications.jrc.ec.europa.eu/repository/handle/JRC118163.
38. Choudhury A, Behl A, Sheorey PA, Pal A. Digital supply chain to unlock new agility: a TISM approach. *Benchmarking: An International Journal*. 2021;28(6):2075–2109. Available from: https://doi.org/10.1108/BIJ-08-2020-0461.
39. Attaran M. Digital technology enablers and their implications for supply chain management. *Supply Chain Forum: An International Journal*. 2020;21(3):158–172. Available from: https://doi.org/10.1080/16258312.2020.1751568.
40. Maccarthy BL, Ivanov D. The Digital Supply Chain. In: The Digital Supply Chain—emergence, concepts, definitions, and technologies. 2022;p. 3–24. Available from: https://doi.org/10.1016/B978-0-323-91614-1.00001-0.
41. Gammelgaard B, Nowicka K. Next generation supply chain management: the impact of cloud computing. *Journal of Enterprise Information Management*. 2024;37(4):1140–1160. Available from: https://doi.org/10.1108/JEIM-09-2022-0317.
42. Feng Y, Lai K, Zhu Q. Green supply chain innovation: Emergence, adoption, and challenges. *International Journal of Production Economics*. 2022;248. Available from: https://doi.org/10.1016/j.ijpe.2022.108497.
43. Ni Z, Wu B, Yang Q, Yan LL, Liu C, Shaw RJ. An mHealth intervention to improve medication adherence and health outcomes among patients with coronary heart disease: randomized controlled trial. *Journal of medical Internet research*. 2022;24(3):1–16. Available from: https://doi.org/10.2196/27202.
44. Onukwugha FI, Smith L, Kaseje D, Wafula C, Kaseje M, Orton B, et al. The effectiveness and characteristics of mHealth interventions to increase adolescent's use of sexual and reproductive health services in sub-Saharan Africa: a systematic review. *Plos one*. 2022;17(1):1–18. Available from: https://doi.org/10.1371/journal.pone.0261973.
45. Heneghan MB, Hussain T, Barrera L, Cai SW, Haugen M, Morgan E, et al. Access to technology and preferences for an mHealth intervention to promote medication adherence in pediatric acute lymphoblastic leukemia: approach leveraging behavior change techniques. *Journal of medical Internet research*. 2021;23(2):1–13. Available from: https://doi.org/10.2196/24893.
46. Lee SB, Valerius J. mHealth Interventions to Promote Anti-Retroviral Adherence in HIV: Narrative Review. *JMIR mHealth and uHealth*. 2020;8(8):1–16. Available from: https://doi.org/10.2196/14739.
47. Yang Y, Boulton E, Todd C. Measurement of adherence to mHealth physical activity interventions and exploration of the factors that affect the adherence: scoping review and proposed …. *Journal of Medical Internet Research*. 2022;24(6):1–16. Available from: https://doi.org/10.2196/30817.
48. Wang Q, Su M, Zhang M, Li R. Integrating digital technologies and public health to fight Covid-19 pandemic: key technologies, applications, challenges and outlook of digital healthcare. *International Journal of Environmental Research and Public Health*. 2021;18(11):1–50. Available from: https://doi.org/10.3390/ijerph18116053.
49. Wamsley D, Chin-Yee B. COVID-19, digital health technology and the politics of the unprecedented. *Big Data & Society*. 2021;p. 1–6. Available from: https://doi.org/10.1177/20539517211019441.
50. Petracca F, Ciani O, Cucciniello M, Tarricone R. Harnessing digital health technologies during and after the COVID-19 pandemic: context matters. *Journal of medical Internet research*. 2020;22(12):1–7. Available from: https://doi.org/10.2196/21815.
51. Torous J, Myrick KJ, Rauseo-Ricupero N, Firth J. Digital mental health and COVID-19: using technology today to accelerate the curve on access and quality tomorrow. *JMIR mental health*. 2020;7(3):1–6. Available from: https://doi.org/10.2196/18848.
52. Kadakia K, Patel B, Shah A. Advancing digital health: FDA innovation during COVID-19. *npj digital medicine*. 2020;3:1–3. Available from: https://doi.org/10.1038/s41746-020-00371-7.
53. Peters K, Silva S, Wolter TS, Anjos L, Van Ettekoven N, Éric Combette, et al. UN world food programme: toward zero hunger with analytics. *Informs journal on applied analytics*. 2022;52(1):8–26. Available from: https://doi.org/10.1287/inte.2021.1097.
54. Lehmacher W, Lind M, Van Gogh M, Becha H, Kouwenhoven N, Lund E, et al. Responding to humanitarian and global concerns with digitally enabled supply chain visibility. In: Maritime Informatics. Progress in IS;Springer, Cham. 2021;p. 1–16. Available from: https://doi.org/10.1007/978-3-030-72785-7_1.
55. Sigala IF, Kettinger WJ, and TW. Digitizing the field: designing ERP systems for Triple-A humanitarian supply chains. *Journal of Humanitarian Logistics and Supply Chain Management*. 2020;10(2):231–260. Available from: https://doi.org/10.1108/JHLSCM-08-2019-0049.
56. Koliousis I, He Q, Wu Q, Sarpong D. Using an integrated humanitarian supply chain ERP system to improve refugee flow management: a conceptual framework and validation. *Production Planning & Control*. 2022;33(6-7):676–691. Available from: https://doi.org/10.1080/09537287.2020.1834134.
57. Kabra G, Ramesh A, Jain V, Akhtar P. Barriers to information and digital technology adoption in humanitarian supply chain management: a fuzzy AHP approach. *Journal of Enterprise Information Management*. 2023;36(2):505–527. Available from: https://doi.org/10.1108/JEIM-10-2021-0456.
58. Dohale V, Ambilkar P, Gunasekaran A, Bilolikar V. Examining the barriers to operationalization of humanitarian supply chains: lessons learned from COVID-19 crisis. *Annals of Operations Research*. 2022;335(3):1137–1176. Available from: https://doi.org/10.1007/s10479-022-04752-x.
59. Sahebi IG, Masoomi B, Ghorbani S. Expert oriented approach for analyzing the blockchain adoption barriers in humanitarian supply chain. *Technology in Society*. 2020;63. Available from: https://doi.org/10.1016/j.techsoc.2020.101427.
60. Marić J, Galera-Zarco C, Opazo-Basáez M. The emergent role of digital technologies in the context of humanitarian supply chains: a systematic literature review. *Annals of Operations Research*. 2022;319(1):1003–1044. Available from: https://doi.org/10.1007/s10479-021-04079-z.

61. Ansar S, Kellis M. Optimizing Emergency Medical Logistics to Enhance Healthcare Supply Chain Resilience During Pandemics. . Available from: researchgate.net.
62. Madanian S, Parry D. Identifying the Potential of RFID in Disaster Healthcare: An International Delphi Study. *Electronics* . 2021;10(21):1–20. Available from: https://doi.org/10.3390/electronics10212621.
63. Hamadneh S, Keskin E, Alshurideh M, Al-Masri Y, Kurdi B. The benefits and challenges of RFID technology implementation in supply chain: A case study from the Turkish construction sector. *Uncertain Supply Chain Management*. 2021;9(4):1071–1080. Available from: http://dx.doi.org/10.5267/j.uscm.2021.x.006.
64. Chingono TT, Mbohwa C. Humanitarian Logistics in the Industry 4.0. *Supply Networks in Developing Countries: Sustainable and Humanitarian Logistics in Growing Consumer Markets*. 2023;p. 99–127. Available from: https://doi.org/10.1108/978-1-80117-194-620231009.
65. Sellevold E, May T, Gangi S, Kulakowski J, Mcdonnell I, Hill D, et al. Asset tracking, condition visibility and sustainability using unmanned aerial systems in global logistics. *Transportation Research Interdisciplinary Perspectives*. 2020;8:1–13. Available from: https://doi.org/10.1016/j.trip.2020.100234.
66. Agarwal S, Kant R, Shankar R. Modeling the enablers of humanitarian supply chain management: a hybrid group decision-making approach. *Benchmarking: An international journal*. 2021;28(1):166–204. Available from: https://doi.org/10.1108/BIJ-03-2020-0093.
67. Xu W, Xiong S, Proverbs D, Zhong Z. Evaluation of Humanitarian Supply Chain Resilience in Flood Disaster. *Water* . 2021;13(16):1–21. Available from: https://doi.org/10.3390/w13162158.
68. and ISD. Exploring critical success factors [CSFs] of humanitarian supply chain management [HSCM] in flood disaster management. *Journal of Humanitarian Logistics and Supply Chain Management*. 2022;12(1):129–153. Available from: https://doi.org/10.1108/JHLSCM-01-2021-0003.
69. Clarke PK, Campbell L. Decision-making at the sharp end: a survey of literature related to decision-making in humanitarian contexts. *Journal of International Humanitarian Action*. 2020;5:1–14. Available from: https://doi.org/10.1186/s41018-020-00068-2.
70. Dubey R, Bryde DJ, Foropon C, Graham G, Giannakis M, Mishra DB. Agility in humanitarian supply chain: An organizational information processing perspective and relational view. *Annals of Operations Research*. 2022;319(1):559–579. Available from: https://doi.org/10.1007/s10479-020-03824-0.