OPERATIONS AND SUPPLY CHAIN MANAGEMENT
Vol. 17, No. 3, 2024, pp. 128 - 140
ISSN 1979-3561 | EISSN 2579-9363

Digitalization and the Medical Supply Chain Management: Systematic Literature Review and Bibliometric Analysis

Brian HIATT
Department of Supply Chain Management,
G. Brint Ryan College of Business, University of North Texas, Denton, USA
E-mail: brian.hiatt@unt.edu

Seock-Jin HONG
Department of Supply Chain Management,
G. Brint Ryan College of Business, University of North Texas, Denton, USA
E-mail: seock.hong@unt.edu *(Corresponding Author)*

Ik-Whan G. KWON
Professor Emeritus of Supply Chain Management,
Richard A. Chaifetz School of Business, Saint Louis University, Saint Louis, USA
email: Ikwhan.g.kwon@slu.edu

Michael Savoie
Department of Supplyy Chain Management,
G. Brint Ryan College of Business, University of North Texas, Denton, USA
E-mail: michael.savoie@unt.edu

ABSTRACT

This study uses a systematic literature review and bibliometric analysis to examine the current medical supply chain issues. The goal is to identify past trends and research gaps, focusing on lowering costs, improving efficiency, and eliminating drug shortages or oversupplies through digitalization. This study employs a systematic literature review and bibliometric analysis to identify key terms in medical supply chain academic research, analyzing 51 out of 904 articles from 2,160 publications. Past medical supply chain research has primarily focused on logistics, inventory, and cost management. The COVID-19 pandemic has heightened the complexity of the medical supply chain, highlighting the need for reverse logistics and sustainability while digitalization improves connectivity and resource management. Blockchain technologies are revolutionizing supply chains, improving visibility, reducing costs, enhancing patient satisfaction, and facilitating integrated healthcare systems.

Keywords: *blockchain, digitalization, medical supply chain, resiliency, supply chain risk, sustainability*

1. INTRODUCTION

The cost of healthcare is increasing day by day, but surprisingly, increased spending on healthcare has not led to improved health outcomes (OECD, 2022). In 2018, America spent nearly twice as much as the average OECD country, i.e., 16.9% of its GDP on healthcare, but still, Americans had worse health outcomes than the OECD average (Tikkanea & Abrams, 2020). A study by The Commonwealth Fund (2007) found that the United States had the most expensive healthcare system in the world. However, it consistently underperformed on access, patient safety, and efficiency (Schoenbaum *et al.*, 2007).

From an operations management viewpoint, supply chain management, purchasing, and medicine have produced abundant literature. Given the wealth of research, this vast body of academic studies should translate into practical improvements in the medical supply chain. However, medical and healthcare costs continue to rise, product shortages (especially drugs) persist, and patient outcomes vary significantly between ethnic groups (OECD, 2022; Tikkanea & Abrams, 2020). The healthcare industry has been accused of misunderstanding supply chain management fundamentals (Kwon *et al.*, 2016; Moons *et al.*, 2019). The medical supply chain is critical to the effective functioning of the healthcare system (Hiatt *et al.*, 2023), as it ensures that healthcare providers have access to the equipment and the supplies they need to care for their patients. That is one of the main reasons the medical supply chain is filled with talented individuals seeking to address these issues (Ma *et al.*, 2019). However, the lack of practical improvements in the medical supply chain despite the breadth of academic research raises critical questions:

1. Is there a misunderstanding of supply chain management fundamentals in the healthcare industry?
2. Is there an academic research gap in our understanding of the medical supply chain?

This study conducts a systematic literature review and bibliometric analysis to address the above question, especially to fill the research gap by applying the medical supply chain to the healthcare industry. The research considered two key questions:

1. What is the current medical supply chain research status?
2. Is there a gap in our understanding of the medical supply chain that still needs to be explored?

Prior studies examined these questions using a systematic literature review or a bibliometric analysis independent of each other. While these two methods are similar, some differences exist. Thus, in this study, we compared and contrasted the results from these two research protocols to get a holistic view.

A bibliometric analysis of medical supply chain management highlights the importance of digital technology in improving performance, efficiency, and sustainability. The adoption of blockchain and RFID technologies can enhance employee satisfaction, resilience against disruptions, and customer relationships, ultimately leading to improved competitiveness and enhanced customer relationships. The remaining sections are as follows:

1. Section 2 reviews the current body of medical supply chain literature.
2. Section 3 presents the methodology used and provides a descriptive literature analysis.
3. Section 4 describes the research findings.
4. Section 5 presents the managerial and practical implications.
5. Section 6 concludes the study with limitations and future research opportunities.

2. LITERATURE REVIEW

The medical supply chain is a vast global network of manufacturers, distributors, and healthcare providers that provide goods and services to nearly every population worldwide (Jamil *et al.*, 2019). The range of medical products and services offered is immense and adds complexity to the distribution of medical supplies (Sampson *et al.*, 2015). The flow of medical products, medical services, and patients must all be managed in such a way as to ensure that quality care is provided to the patient while controlling costs (Kwon *et al.*, 2016). Digitalization within medical supply chains using blockchain and RFID has improved connectivity, information flow, and resources, leading to improved performance (Ekezie & Hong, 2024; Lapper *et al.*, 2018; Kim & Kim, 2019). Digitizing medical supply chain management can create a competitive advantage for organizations by improving employee satisfaction and customer relationships (Lapper *et al.*, 2018; Martins *et al.*, 2020). Some of the unique characteristics of the medical supply chain are discussed below.

Ever-increasing complexity and uncertainty within the medical supply chain requires supply chain professionals to be responsible for increasingly complex decision-making. A significant challenge in the decision-making process within the medical supply chain is the number of stakeholders and their conflicting goals (Abdulsalam *et al.*, 2015). Key stakeholders include manufacturers, insurance companies, hospitals, healthcare providers, group purchasing organizations (GPOs), various regulatory bodies, and patients (Sakly *et al.*, 2021).

Manufacturers, suppliers, and distributors often focus on profit-seeking activities and may not align with hospitals, doctors, and other frontline healthcare providers (McKone-Sweet *et al.*, 2005). This misalignment of goals and priorities can increase complexity and costs and decrease supply chain efficiency (Min & Mentzer, 2000). Supply chain costs per transaction are higher within the medical supply chain than in the commercial supply chain (Kwon *et al.*, 2016). Costs within the medical supply chain have been examined in depth at the manufacturing and hospital level (Mandal, 2017; Moons *et al.*, 2019).

Digitalization in healthcare involves tracking item-level traceability from receipt to patient use, aiming to save money and ensure patient safety. Automated inventory management, including mobile inventory applications and RFID technologies, captures accurate usage and demand evaluations, enhancing restocking procedures. Digitalization results in accurate analytics, promoting return on investment and facilitating transformation and financial savings (Chorfi *et al.*, 2018; Iannone *et al.*, 2014).

Over the past decade, a considerable focus has been on improving inventory management in the medical supply chain through digitalization (Labuhn *et al.*, 2017; Sadjadi *et al.*, 2019). Researchers and practitioners have conducted studies showing how digitalized inventory projects in hospital pharmacies have reduced stockouts and costs. The improvements have been possible because of the collaborative efforts of medical teams, optimized process improvement teams, and industrial engineering teams (Labuhn *et al.*, 2017). Centralized hospital pharmacies have been particularly effective in increasing performance and reducing costs (Ekezie & Hong, 2024; Iannone *et al.*, 2014). Researchers have also looked into vaccine distribution, medical nuclear supply chains, and transplant organ transportation (Nagurney *et al.*, 2015; Paganelli *et al.*, 2019; Sadjadi *et al.*, 2019).

Stockouts in the medical supply chain can negatively impact patient outcomes (Mustaffa & Potter, 2009; Wilding, 1998). Therefore, inventory managers aim to minimize their impact. Healthcare providers must maintain appropriate inventory levels through digitalization to avoid shortages or waste from expired medical inventory, which can be challenging (Zhang *et al.*, 2022).

Minimizing patient risks and ensuring quality care are essential in producing and distributing medical supplies (Mandal, 2017). Since the COVID-19 pandemic, much medical supply risk management research has focused on disruption risks and the resulting stockouts (Friday *et al.*, 2021; Hohenstein, 2022). Research shows that collaboration between and among key stakeholders can help to reduce stockout risks (Friday *et al.*, 2021). Additionally, ensuring supply chain visibility and adopting a holistic approach to supply chain management has improved performance (Ekezie & Hong, 2024; Hohenstein, 2022).

Medical supplies represent a large spectrum of products, such as pharmaceuticals, medical devices, surgical items, medical diagnostic equipment, and personal protective equipment (Lee & Fernando, 2015; Sakly *et al.*, 2021). Poor quality in any of these items can have a direct and sometimes fatal effect (Mandal, 2017). While manufacturers understand the importance of product quality, they are also concerned that too much effort paid to quality may hurt business profits (Ma *et al.*, 2019). Pharmaceutical companies recognize the importance of product quality in protecting their reputation and enhancing the organization's competitive advantage (Chen *et al.*, 2020). Higher product quality also increases production costs, which are then passed on to customers.

To minimize the negative impact of disruptions, medical supply chains must be resilient (Spieske *et al.*, 2022). Organizations that improve their supply chain resilience help ensure they are not the weak link in the medical supply chain (Pettit *et al.*, 2019). Establishing long-term buyer-supplier relationships is more effective for increasing resilience than other preventive measures (Spieske *et al.*, 2022). Studies investigating resilience within medical equipment and vaccine supply chains find that collaboration, information sharing, and trust affect the healthcare supply chain's resilience (Zamiela *et al.*, 2022).

Sustainability within the medical supply chain is gaining attention from governments, practitioners, and researchers (Chen *et al.*, 2020; Zamiela *et al.*, 2022). AI-enhanced medical drone applications contribute significantly to meeting the WHO's sustainable development goals (Damoah *et al.*, 2021). Waste reduction and reducing energy consumption are essential to sustainability (Chen *et al.*, 2020). Medical waste is grouped into one of three categories based on its level of hazardousness: non-hazardous or general medical waste, hazardous or infectious medical waste, and chemical and pharmaceutical waste (Gabriel *et al.*, 2018). The reverse logistics network for medical waste is a crucial focus of sustainability efforts and involves sterilization, collection, recycling, and destruction centers (Alizadeh *et al.*, 2020).

3. METHODOLOGY

This study employed a two-methodology approach to answering the stated research questions:

1. What is the status of current medical supply chain research?
2. Is there a gap in our understanding of the medical supply chain that still needs to be explored?

First, a systematic literature review was conducted to identify critical scientific contributions in the field of the medical supply chain (Tranfield *et al.*, 2003). Second, a bibliometric analysis was conducted to identify knowledge gaps in the field (Donthu *et al.*, 2021).

3.1 Systematic Literature Review (Method 1)

The systematic literature review (SLR) methodology was first used in the medical sciences to enhance the legitimacy of findings and minimize bias in literature reviews by providing a reproducible, scientific, and transparent process (Tranfield *et al.*, 2003). The SLR is a rigorous process of systematically locating and collating all available information on a topic for analysis (Davis *et al.*, 2014). Unlike traditional literature reviews, SLRs are comprehensive by including all relevant studies across scientific disciplines (Rousseau *et al.*, 2008). This study follows the SLR methods outlined by Denyer and Tranfield (2009) and the content analysis-based literature review method according to Seuring and Gold (2012).

3.1.1 Data Collection and Selection

Data collection begins with the identification of search terms and a selection of databases for analysis. Consistent with SLR in the medical supply chain, this study used defined keywords as the search criteria. The keywords were "medical supply chain" OR "healthcare supply chain." Given the multidisciplinary nature of the medical supply chain, it was deemed essential to include various databases. Searching for articles in various databases helps to ensure a comprehensive list of articles. This study used three online databases with peer-reviewed journals: EBSCO Host, Scopus, and ABI/Inform from 2021. A total of 1,268 articles were identified during the initial search: 353 articles from EBSCO Host, 609 from Scopus, and 306 from ABI/Informs.

In order to focus on the research topic, all identified articles underwent a screening process; 584 duplicate articles were removed from 1,268 articles. The 684 remaining articles were then evaluated using a two-step process. First, the title and abstract of the selected article were analyzed according to the pre-defined inclusion and exclusion criteria. This process eliminated 446 articles. Second, the remaining 238 articles were read to determine if they should be included or excluded in the final collection.

Articles that focused on the medical supply chain as a whole or in part and those that focused on medical logistics were included in the final collection. Articles that only minimally referred to the medical supply chain and simulation articles were excluded from the final collection. This process eliminated an additional 34 articles, leaving 204 articles. Eight additional articles cited in the reports were reviewed and found appropriate for inclusion in the final sample. The final sample of 212 articles represents works published since 2001 in 146 peer-reviewed journals. The article selection process is depicted in **Figure 1**.

3.1.2 Keyword Analysis

Keywords were analyzed to identify key scientific contributions in the field. The author(s) provided keywords extracted from each article. Of the 212 articles, a total of 807 keywords were identified. Next, the keyword list was revised to include terms relating to supply chain management. Dropping non-supply chain-related terms helps to reveal key scientific contributions relating to medical supply chain management and logistics.

3.1.3 Keyword Co-occurrence Networks

We apply keyword co-occurrence network analysis to the SLR/bibliometric articles. The keyword co-occurrence network is a quantitative bibliometric method (Waltman *et al.*, 2010). In a keyword co-occurrence network, each keyword represents a node, while each co-occurrence of a pair of words represents the links between keywords in the literature (Do *et al.*, 2021). Weights are assigned to each link based on the number of times a pair of words co-occurs (Cheng *et al.*, 2018). Networks constructed using this method represent a domain's collective knowledge, which helps to reveal significant knowledge and insights based on the patterns and links between keywords that appear in the literature (Radhakrishnan *et al.*, 2017). The keyword co-occurrence network reveals research trends and the conceptual or knowledge structure of the literature, like those discovered through a formal systematic review (Donthu *et al.*, 2020).

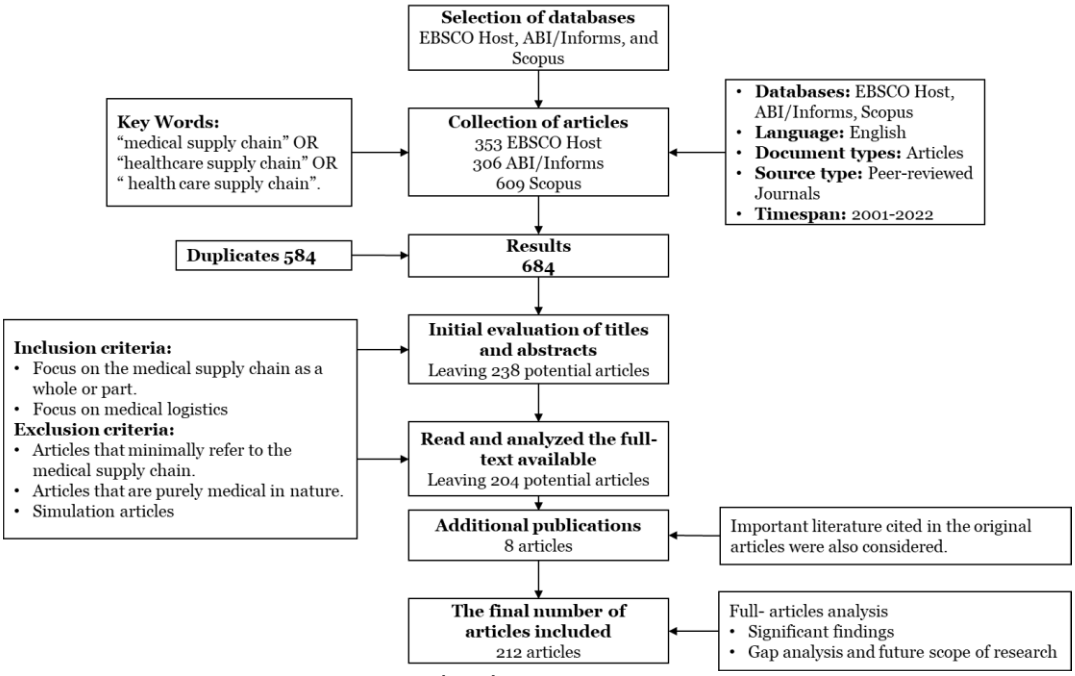

Figure 1 Research flow for the systematic literature review

VOSviewer, a bibliometric software tool, creates co-occurrence networks from bibliographic database files, which can create maps based on network data and visualize to explore the maps (Eck & Waltman, 2021). The VOSviewer's algorithm assigns weights to each keyword based on the number of links and total strength of the links (Donthu *et al.*, 2020). Related keywords are then divided into clusters and graphically displayed. Keywords grouped in the same cluster are strongly associated and refer to the same topic (Do *et al.*, 2021). The size of the nodes reflects the occurrence of the keyword, and the lines connecting the nodes represent the relevance and strength of the association (Donthu *et al.*, 2020).

3.2 Bibliometric Analysis (Method 2)

Bibliometric analysis was first used in library and information science to analyze large volumes of published articles (Donthu *et al.*, 2020). SLRs follow a strict systematic process to collect articles, and then a qualitative approach is used to synthesize the findings (Snyder, 2019). A fundamental limitation when conducting SLRs is the number of articles a research team can reasonably review. Using sophisticated software such as VOSviewer, bibliometric studies are not limited by the number of articles to be reviewed.

Both SLRs and bibliometric studies can help to advance a field by identifying knowledge gaps and deriving novel ideas for future investigation (Tranfield *et al.*, 2003). A multi-method study using SLRs and bibliometric analysis makes it possible to conduct a qualitative analysis of a single field. Bibliometric analyses do not require an extensive exclusion process to reduce the articles to a manageable number. Once the duplicate articles are removed, bibliometric studies use quantitative techniques to decipher and map large volumes of unstructured data for scientific discovery (Donthu *et al.*, 2021).

3.2.1 Data Collection and Selection

The same search terms were used for the bibliometric analysis as in the SLR. The set of keywords consisted of the phrase "medical supply chain" OR "healthcare supply chain" OR "health-care supply chain". Given the multidisciplinary nature of the medical supply chain, it is important to include a variety of databases. Web of Science and Scopus databases were chosen to ensure a comprehensive list of articles. As noted earlier, articles were limited to those published since 2001. Consistent with the methodology used in the SLR, the keywords were searched for in the article title, abstract, or author-provided keywords. During the initial search, 892 articles were identified: 283 from Web of Science and 609 from Scopus.

3.2.2 Keyword Co-occurrence Network Analysis

For this analysis, 892 articles were loaded into VOSviewer; 263 duplicates were removed, leaving 629 articles to be analyzed. Initial analysis identified 2,091 keywords within the 692 articles (see **Figure 2**). These keywords were identified with similar meanings but in different formats (e.g., supply chain and supply chains, coronavirus disease 2019, and COVID-19). A thesaurus file was created, enabling the software tool to merge terms during subsequent analysis.

4. RESEARCH RESULTS

In total, 841 articles were analyzed to answer the research questions: 212 as part of the SLR and 629 as part of the bibliometric analysis. Most articles were published in the past five years. Since 2017, 680 articles on the medical supply chain have been published. Data and insights were extracted from each article to further our understanding of the medical supply chain and not simply recite previous research (Snyder, 2019).

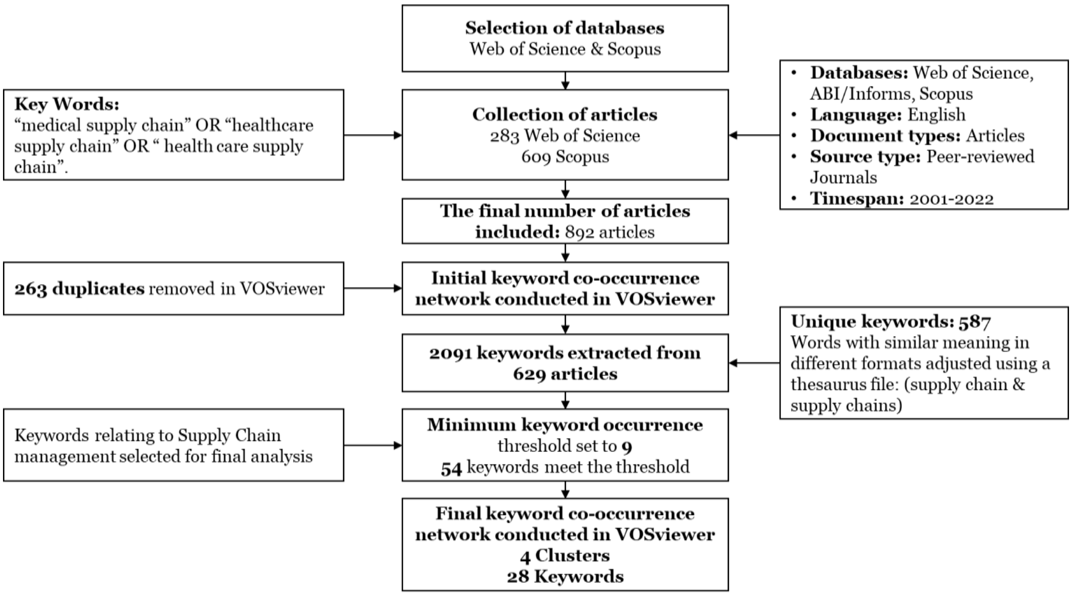

Figure 2 Research flow for the bibliometric analysis

4.1 Method 1: Slr Keyword Co-occurrence Network

A keyword co-occurrence network with the article titles, abstracts, and keywords was created using VOSviewer. We extracted 807 keywords from the 212 articles that occurred at least three times. Establishing an appropriate threshold number allows us to exclude the keywords with low occurrences, and thus, the network becomes more concentrated and focused (Do *et al.*, 2021). Thirty-four keywords relating to supply chain management occurred at least three times. These keywords were selected for the final analysis. The final keyword co-occurrence network comprised three clusters (see **Figure 3**).

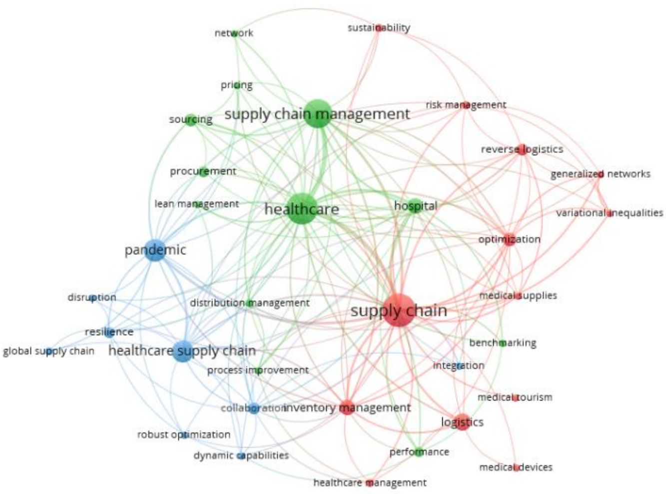

Figure 3 Method 1 (SLR) keyword co-occurrence network with four cluster

4.1.1 Cluster 1: Supply Chain and Logistics

This cluster consists of 13 keywords (see **Table 1**) that show 243 strengths (40.4% among the three clusters) and 128 occurrences (36.3%). Among the 13 keywords, "Supply chain" shows the highest strength and occurrences, followed by "Inventory management, optimization, and reverse logistics." These four keywords show 69.1% strength and 67.2% occurrence.

It is curious to note that the VOSviewer software identified 'supply chain' and 'supply chain management' as two distinct terms despite their similarities. Additionally, the keyword co-occurrence network placed the two terms in different clusters. The term supply chain refers to a network composed of raw material suppliers, producers, distributors, and final consumers (Liao & Widowati, 2021). Whereas the term supply chain management refers to the managerial process of managing the flow of good from point of origin to the point of consumption (Wahab et. al., 2023) and the activity of improving the efficiency and effectiveness of the supply chain in part or as a whole.

Medical supply chains have characteristics of reverse logistics (6.6% of strength and 5.5% of occurrence) because of medical waste. The healthcare provider is responsible for identifying and disposing of all medical waste, including sterilization, collection, recycling, and destruction centers (Alizadeh *et al.*, 2020). Pharmaceutical waste moves upstream from the pharmacist or healthcare provider to the distributor, who sorts and documents it for disposal or sends it back to the manufacturer.

4.1.2 Cluster 2: Healthcare & Supply Chain Management

This cluster consists of 12 keywords (see **Table 2**) that show 242 strengths (40.3% among the three clusters) and 145 occurrences (41.1%). Among the keywords, "Healthcare" shows the highest strength and occurrences, followed by "Supply Chain Management and Hospital." These three keywords together yield 73.6% of strength and 73.8% of occurrences. The focus on individual supply chains is often unique at a micro level of the supply chain. Some supply chains emphasize efficiency, while others focus on effectiveness (Dolinskaya *et al.*, 2018; Kwon & Hong, 2011). Profit-seeking activities may not align with manufacturers, insurance companies, hospital managers, and GPOs (Sakly *et al.*, 2021), which can increase the complexity of the medical supply chain and decrease its efficiency (Mentzer *et al.*, 2000). Healthcare-related organizations apply lean management (Kim & Kim, 2019), process improvement, benchmarking, and performance measurement applying digitalization. Digitalization enhances medical supply chain performance, employee satisfaction, and customer relationships, providing a competitive advantage for organizations through efficient management and improved connectivity (Kim & Kim, 2019; Martins *et al.*, 2020). The COVID-19 pandemic has exposed the dependence on few sources, which increases the challenges within medical supply chains.

Table 1 Keywords for cluster 1 of method 1 – supply chain & logistics

Cluster 1 (Red) – Supply Chain & Logistics						
Keyword	**Strength**	**%**	**Accumulative %**	**Occurrences**	**%**	**Accumulative %**
Supply Chain	94	38.7%	38.7%	57	44.5%	44.5%
Inventory Management	31	12.8%	51.44%	12	9.4%	53.91%
Optimization	27	11.1%	62.55%	10	7.8%	61.72%
Reverse Logistics	16	6.6%	69.14%	7	5.5%	67.19%
Logistics	14	5.8%	74.90%	15	11.7%	78.91%
Medical Supplies	12	4.9%	79.84%	3	2.3%	81.25%
Risk Management	11	4.5%	84.36%	4	3.1%	84.38%
Variational Inequalities	11	4.5%	88.89%	3	2.3%	86.72%
Generalized Networks	11	4.5%	93.42%	3	2.3%	89.06%
Healthcare Management	6	2.5%	95.88%	4	3.1%	92.19%
Sustainability	6	2.5%	98.35%	4	3.1%	95.31%
Medical Devices	2	0.8%	99.18%	3	2.3%	97.66%
Medical Tourism	2	0.8%	100.00%	3	2.3%	100.00%
Total	243	100%		128	100%	

Table 2 Keywords for cluster 2 of method 1 – healthcare & supply chain management

Cluster 2 (Green) – Healthcare & Supply Chain Management						
Keyword	**Strength**	**%**	**Accumulative %**	**Occurrences**	**%**	**Accumulative %**
Healthcare	87	36.0%	36.0%	50	34.5%	34.5%
Supply Chain Management	58	24.0%	59.92%	44	30.3%	64.83%
Hospital	33	13.6%	73.55%	13	9.0%	73.79%
Sourcing	15	6.2%	79.75%	8	5.5%	79.31%
Performance	9	3.7%	83.47%	5	3.4%	82.76%
Distribution Management	8	3.3%	86.78%	4	2.8%	85.52%
Process Improvement	7	2.9%	89.67%	3	2.1%	87.59%
Procurement	6	2.5%	92.15%	6	4.1%	91.72%
Pricing	6	2.5%	94.63%	3	2.1%	93.79%
Network	5	2.1%	96.69%	3	2.1%	95.86%
Benchmarking	4	1.7%	98.35%	3	2.1%	97.93%
Lean Management	4	1.7%	100.00%	3	2.1%	100.00%
Total	242	100%		145	100%	

Table 3 Keywords for cluster 3 of method 1 – pandemic & disruption

Cluster 3 (Blue) – Pandemic & Disruption						
Keyword	**Strength**	**%**	**Accumulative %**	**Occurrences**	**%**	**Accumulative %**
Pandemic	36	31.0%	31.0%	26	32.5%	32.5%
Healthcare Supply Chain	25	22.6%	52.59%	25	31.3%	63.75%
Collaboration	18	15.5%	68.10%	7	8.8%	72.50%
Resilience	12	10.3%	78.45%	6	7.5%	80.00%
Dynamic Capabilities	7	6.0%	84.48%	3	3.8%	83.75%
Disruption	5	4.3%	88.79%	3	3.8%	87.50%
Integration	5	4.3%	93.10%	3	3.8%	91.25%
Global Supply Chain	4	3.4%	96.55%	4	5.0%	96.25%
Robust Optimization	4	3.4%	100.00%	3	3.8%	100.00%
Total	116	100%		80	100%	

4.1.3 Cluster 3: Pandemic and Disruption

This cluster consists of nine keywords (see **Table 3**) that show 116 strengths (19.3% among the three clusters) and 80 occurrences (22.7%). Among the keywords, "Pandemic" shows the highest strength and occurrences, followed by "Healthcare supply chain, collaboration, and resilience." These four keywords show 78.5% of strength and 80.0% of occurrences.

COVID-19 has catapulted the medical supply chain disruption study from a niche domain into the mainstream. During the pandemic, humanitarian medical aid and disaster response research primarily focused on delivering care (Dolinskaya *et al.*, 2018). This focus on just a single echelon leaves a wide research gap. Little is known about the procurement and distribution strategies required to provide rapid medical assistance to those in need. The medical supply chain can be vulnerable to disruptions, such as natural disasters, pandemics, or geopolitical events, impacting the attainability and cost of medical supplies (Hiatt *et al.*, 2023; Kilpatrick & Barter, 2020). When facing unpredictable environments, supply chain collaboration has been regarded as a clear strategy to gain comparative advantages by integrating all resources to create enough resiliency (Zhang *et al.*, 2021; Zhang *et al.*, 2019). Therefore, the medical supply chain uses various capacities and capabilities, ensuring both customers' expectations and stakeholders' benefit.

4.2 Method 2: Bibliometric Analysis Keyword Co-occurrence Network

A keyword co-occurrence network was created by first identifying articles following the methodology outlined in Section 3. Due to the software limitations of VOSviewer, only Web of Science and Scopus databases were used for this analysis. As stated earlier, a total of 2,091 keywords were extracted from 629 articles. Establishing appropriate threshold numbers excludes the keywords with low occurrences, and thus, the network becomes more concentrated (Do *et al.*, 2021). Fifty-four keywords occurred at least eight times and were used for analysis. Only 28 keywords relating to supply chain management were chosen for the final analysis. The final keyword co-occurrence network is comprised of four clusters (see **Figure 4**).

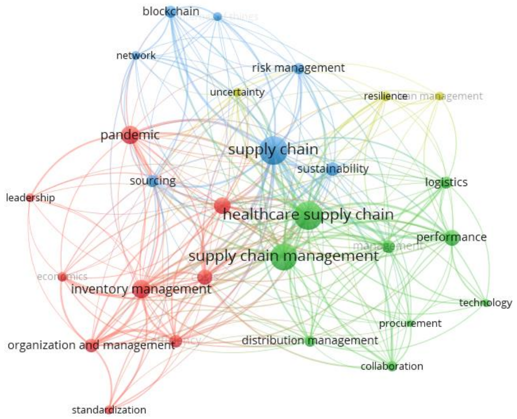

Figure 4 Method 2 (Bibliometric analysis) keyword co-occurrence network with four clusters

4.2.1 Cluster 1: Medical Supply Chain & Performance

This cluster consists of nine keywords (see **Table 4**) that show 729 strengths (37.6% among four clusters) and 332 occurrences (40.2%). Among these keywords, "Healthcare supply chain" shows the highest strength and occurrences, followed by "Supply chain management, performance, and management." These four keywords show 74.9% of strength and 79.2% of occurrences.

Table 4 Keywords for cluster 1 of method 2 – medical supply chain performance

Cluster 1 (Green) – Medical Supply Chain Performance						
Keyword	Strength	%	Accumulative %	Occurrences	%	Accumulative %
Healthcare Supply Chain	215	29.5%	29.5%	107	32.2%	32.2%
Supply Chain Management	173	23.7%	53.2%	99	29.8%	62.0%
Performance	81	11.1%	64.3%	34	10.2%	72.3%
Management	77	10.6%	74.9%	23	6.9%	79.2%
Logistics	47	6.4%	81.3%	19	5.7%	84.9%
Collaboration	45	6.2%	87.5%	15	4.5%	89.5%
Distribution Management	42	5.8%	93.3%	18	5.4%	94.9%
Technology	25	3.4%	96.7%	9	2.7%	97.6%
Procurement	24	3.3%	100.0%	8	2.4%	100.0%
Total	729	100.0%		332	100.0%	

Medical supply chain studies in the healthcare industry have covered supply chains in academic medical centers (Labuhn *et al.*, 2017), the medical devices supply chain (Denton & Jaska, 2014), the dental supply chain (Meier & Lenkenhoff, 2013), the medical equipment supply chain (de Jong & Benton, 2019), and the medical nuclear supply chain (Nagurney *et al.*, 2015). These studies identify the link between supply chain performance, cost reduction, and quality. In medical supply chains, more emphasis is placed on quality and patient outcomes than on cost (Ma *et al.*, 2019). This patient-centric focus has led researchers to seek modified performance measurement systems for the medical supply chain (Chorfi *et al.*, 2018). Additionally, cost savings in logistics could be used to improve patient quality (Kwon *et al.*, 2016). Effective management, including digitalization, process optimization, benchmarking, and performance assessment, significantly improves healthcare supply chain performance, enhancing customer interactions and staff satisfaction (Dolinskaya *et al.*, 2018; Kwon & Hong, 2011; Martins *et al.*, 2020).

4.2.2 Cluster 2: Inventory Management & Decision Making

This cluster is composed of nine keywords (see **Table 5**) that show 637 strengths (32.8% among four clusters) and 246 occurrences (29.8%). Among these keywords, "Inventory management" shows the highest strength and occurrences, followed by "Decision making, costs, and pandemic." These four keywords show 62.5% of strength and 63.4% of occurrences.

Supply chain costs in healthcare are estimated to be 38% of the total expense compared to 5% in the retail industry and 2% in the electronics industry (Johnson, 2015). Several factors have been identified for this disparity in costs—the inefficient use of transportation and warehouse assets, perishability of products such as blood and organs, short expiration dates (e.g., short product life cycle), and supply and demand uncertainty (Asadpour *et al.*, 2022). The COVID-19 pandemic has accelerated the pace of medical supply chain research focusing on inventory management and efficiency (Hiatt *et al.*, 2023; Skipworth *et al.*, 2020).

Table 5 Keywords for cluster 2 of method 2 – inventory management and decision making

Cluster 2 (Red)-Inventory Management & Decision Making						
Keyword	**Strength**	**%**	**Accumulative %**	**Occurrences**	**%**	**Accumulative %**
Inventory Management	122	19.2%	19.2%	44	17.9%	17.9%
Decision Making	103	16.2%	35.3%	37	15.0%	32.9%
Costs	89	14.0%	49.3%	30	12.2%	45.1%
Pandemic	84	13.2%	62.5%	45	18.3%	63.4%
Organization and Management	81	12.7%	75.2%	26	10.6%	74.0%
Efficiency	79	12.4%	87.6%	22	8.9%	82.9%
Economics	39	6.1%	93.7%	12	4.9%	87.8%
Standardization	24	3.8%	97.5%	19	7.7%	95.5%
Leadership	16	2.5%	100.0%	11	4.5%	100.0%
Total	637	100.0%		246	100.0%	

Table 6 Keywords for cluster 3 of method 2 – digital supply chain & sustainability

Cluster 3 (Blue) – Digital Supply Chain & Sustainability						
Keyword	**Strength**	**%**	**Accumulative %**	**Occurrences**	**%**	**Accumulative %**
Digital Supply Chain	240	48.5%	48.5%	109	50.9%	50.9%
Sustainability	63	12.7%	61.2%	24	11.2%	62.1%
Sourcing	51	10.3%	71.5%	21	9.8%	72.0%
Blockchain	47	9.5%	81.0%	21	9.8%	81.8%
Risk Management	45	9.1%	90.1%	18	8.4%	90.2%
Network	26	5.3%	95.4%	11	5.1%	95.3%
Internet of Things	23	4.6%	100.0%	10	4.7%	100.0%
Total	495	100.0%		214	100.0%	

Table 7 Keywords for cluster 4 of method 2 – resiliency

Cluster 4: (Yellow) - Resiliency						
Keyword	**Strength**	**%**	**Accumulative %**	**Occurrences**	**%**	**Accumulative %**
Resilience	33	41.8%	41.8%	13	39.4%	39.4%
Uncertainty	32	40.5%	82.3%	10	30.3%	69.7%
Lean Management	14	17.7%	100.0%	10	30.3%	100.0%
Total	79	100.0%		33	100.0%	

4.2.3 Cluster 3: Digital Supply Chain & Sustainability

This cluster is composed of seven keywords (see **Table 6**) that show 495 strengths (25.5% among four clusters) and 214 occurrences (25.9%). Among these keywords, “Inventory management” shows the highest strength and occurrences, followed by “Decision making and costs.” These three keywords show 49.3% of strength and 45.1% of occurrences.

The medical supply chain faces similar external influences as any other supply chain. External factors include the regulatory environment and technological developments (Skipworth *et al.*, 2020). Medical supplies, including medical donations during a humanitarian crisis, are subject to the local and federal regulations and guidelines of the World Health Organization (Dolinskaya *et al.*, 2018; Kwon *et al.*, 2016). Technological advances such as RFIDs, IoT, blockchain, drones, and AI have all impacted how the digitized medical supply chain operates (Jamil *et al.*, 2019; Purtell *et al.*, 2024; Safkhani *et al.*, 2020). Blockchain technology offers product traceability from material provider to manufacturer (Jamil *et al.*, 2019), aiding in investigations into drug abuse (Lapper *et al.*, 2018). By adopting RFID and digitizing the supply chain, healthcare providers and vendors can improve visibility into consignment inventory and adjust inventory movement in real-time to areas experiencing shortages (Lapper *et al.*, 2018). These digital technological advances present a variety of opportunities for the medical supply chain. Adopting and effectively implementing the digital technologies can help healthcare organizations reduce costs and improve patient outcomes (Spieske *et al.*, 2022). Healthcare organizations are embracing digital supply networks to manage resources and reduce costs. This shift from volume to value reduces errors and variability, allowing employees to focus on higher-value activities. Efficient digital supply chains save hospitals money, increase patient satisfaction, and reduce waiting times (Lapper *et al.*, 2018).

4.2.4 Cluster 4: Resiliency

This cluster consists of three keywords (see **Table 7**) that show 79 strengths (4.1% among four clusters) and 33 occurrences (4.0%). Among the three keywords, “Resilience” shows the highest strength and occurrences, followed by “Uncertainty and lean management.”

The risk of disruption to the medical supply chain has led to the stockpiling of medical products (Skipworth *et al.*, 2020). Emergency stockpiles are intended to increase resilience during supply chain disruptions or spikes in demand during emergencies and pandemics (Dasaklis *et al.*, 2017; Fernandes *et al.*, 2022; Hiatt *et al.*, 2023). The cost to procure and store emergency stockpiles is often challenging, particularly in low and middle-income countries (Fernandes *et al.*, 2022). As costs increase in medical supply chains, many organizations have adopted lean management strategies (Kim & Kim, 2019), including increasing supplier transparency and coordination. Digital supply network strategies can help to reduce costs, waste, and inefficiencies and improve patient satisfaction (Lapper *et al.*, 2018; Moons *et al.*, 2019) toward a broad, enterprise-level digital transformation to enable seamless, integrated health care by investing in new technologies such as blockchain to improve tracking and traceability (Jamil *et al.*, 2019).

5. DISCUSSION

Since the COVID-19 pandemic, interest in the medical supply chain by the public and academia has increased. However, medical supply chain research is still in its early stages, and there are still gaps in our understanding. To identify these gaps, we must first identify the focus of past research. The keyword co-occurrence and cluster analysis using Methods 1 and 2 show that supply chain and logistics with inventory and performance (as in **Tables 1, 2, 4, and 5**) have been the focus of past medical supply chain research.

Given the rising healthcare costs in the United States, the focus on cost is appropriate and understandable. Healthcare supply chain costs are estimated at 38% of the total expense (Johnson, 2015). One factor contributing to the high cost is the reliance on cold chain supply chains (CLSC). CLSC maintain optimal temperatures and humidity levels that guarantees the products' safety and preserve their value (Hassan *et al.,* 2021). CLSC are more costly than traditional supply chains, yet they are required for many medicines, blood, and vaccines. The inventory costs at U.S. hospitals account for approximately one-fourth of total expenses (Saha *et al.*, 2019). The impact of transportation on the medical supply chain is an area that needs more attention. Transportation costs can account for nearly 60% of a company's total logistics costs (Lafkihi *et al.,* 2019). Yet, given that many medical items such as prescription drugs, have a high value to weight ratio, the actual cost of transportation remains unknown. Additionally, various products require different transportation methods, resulting in wide range of transportation cost. For example, bandages and general medical items do not require any special handling and can be transported through the supply chain via traditional methods. While many drugs require a CLSC, and some drugs such as newly developed biologics, have a very short shelf life and require both a CLSC and rapid transportation. Given the focus on costs in the medical supply chain, it is surprising that there remains a gap in our knowledge regarding medical inventory and transportation in the medical supply chain. Implementing digitalization and centralized hospital pharmacies has significantly improved performance and reduced costs, enhancing patient outcomes and overall quality and resulting in substantial cost savings (Chorfi *et al.*, 2018; Iannone *et al.*, 2014; Kim & Kim, 2019; Kwon *et al.*, 2016). Digital supply network strategies are being adopted to reduce costs, improve patient satisfaction, and enable a seamless, integrated healthcare system through investments in blockchain technologies (Lapper *et al.*, 2018). Whereas RFID usage improves real-time inventory adjustment, allowing vendors and healthcare providers to respond to shortages, blockchain technology increases supply chain visibility and supports investigations into drug misuse (Jamil *et al.*, 2019; Lapper *et al.*, 2018).

Research on medical supply chains has been expedited by the COVID-19 pandemic (**Table 3**), focusing on disruption risks and stockouts (Hohenstein, 2022). It has revealed the reliance on a few sources, raised resilience (**Table 7**) and problems in medical supply chains, and sped up inventory management and efficiency (Hiatt *et al.*, 2023). Risk management has been identified as a vital component of an effective and efficient supply chain (Mentzer *et al.*, 2000). The medical supply chain is a complex network, which leads to slower supplier response times, higher transaction costs, and higher supply chain risks (Choi & Krause, 2006). The supply chain priorities of healthcare systems are moving to resiliency and reliability. After years of shifting procurement overseas to pursue lower pricing, the risks of depending on global supply chains are susceptible to production and shipping interruptions (Vizient, 2022). Reliable supply chains with balanced sourcing of domestic and offshore suppliers put healthcare providers in a better position to withstand disruptions and support delivering high-quality patient care (Vizient, 2022).

The healthcare sector prioritizes sustainability (**Table 6**) by utilizing AI-enhanced drone applications to achieve the World Health Organization's Sustainable Development Goals, enhancing visibility from manufacturing to patient care through reusable products and waste reduction (Conway, 2023; Damoah *et al.,* 2021). Reverse logistics (**Tables 1 and 6**) is essential in any supply chain, but more so in the medical supply chain. In the medical supply chain, the role of reverse logistics is increasing due to the complexities associated with medical waste. The risk associated with reverse logistics, the role of the reverse logistics third-party provider, and the impact of reverse logistics on healthcare costs remain unexplored.

Technology is not only connecting medical supply chain partners, but also connecting doctors to patients. Often referred to as telehealth, which is defined as; the integrated communication system in healthcare services (Kuntardjo, 2020). These communication systems include telephones, and online video services. While enabled by technology, the global Covid-19 pandemic acted a catalyst to drive the widespread adoption of telehealth. Telehealth is helping to provide better medical service to people in remote areas or hard to reach areas (Kuntardjo, 2020). This helps to reduce the need for transporting patients to and from medical appointments. Additionally, it also facilitates epidemiological research that can help guide the future of health care (Blandford et. al., 2020).

The focus of supply chain research is often on product flows from the distributor to the end user (**Tables 1, 2, and 4**). However, the flow of information and funds is critical for all supply chains. Understanding how information and funds flow through the medical supply chain may reveal bottlenecks, waste areas, or improvement opportunities. Information and financial flows should be researched in depth to truly understand how to reduce costs within the medical supply chain.

5. CONCLUSION

This research applied a systematic literature review and bibliometric analysis to create a comprehensive keyword co-occurrence network on the medical supply chain. We apply these two methods to expand the medical supply chain literature review. This study makes several notable contributions to the body of medical supply chain literature:

1. The study explored the current state of medical supply chain research, expanding our understanding of the current medical supply chain environment and helping us better understand the system.
2. The study identified the focus of past research on medical supply chains and provides a foundation upon which future research can be built.

As the medical supply chain's collective knowledge increases, it will lead to practical and theoretical contributions extending beyond healthcare (Abdulsalam *et al.*, 2015). This study only considered articles published in peer-reviewed journals. The inclusion and exclusion criteria used in this study were carefully developed to answer this study's research questions. While the resulting sample did yield exciting findings, there is a possibility that a small portion of the excluded articles may offer additional insights.

Through a systematic literature review and bibliometric analysis of medical supply chain management, we have found that cost, performance, efficiency, sustainability, resilience, and blockchain are commonly discussed topics. The implementation of digital technology in medical supply chain management can improve an organization's competitiveness by reducing costs, boosting performance and efficiency, increasing resilience against disruptions, enhancing employee satisfaction, and improving relationships with customers. This, in turn, leads to enhanced customer relationships externally. Digital technology includes the adoption of blockchain, RFID, and other technologies (Chorfi *et al.*, 2018; Lapper *et al.*, 2018; Sadjadi *et al.*, 2019). The COVID-19 pandemic has heightened research on the medical supply chain, revealing its complexity and potential disruption. Reverse logistics and sustainability are prioritized in the healthcare industry.

This review and analysis have also helped to identify several areas for future research. Understanding information flow throughout the medical supply chain is crucial for identifying bottlenecks and improving outcomes. Future research can explore how information flows through the medical supply chain and its impact on outcomes. Digitalization has enhanced the global medical supply chain, enhancing connectivity, information flow, and resource management, providing a competitive advantage, and improving quality care. Future research can explore practical problems like cost control and risk management. The medical supply chain operates in various settings, providing researchers with ample case studies.

Medical waste processing and nuclear waste management are additional areas of future research that could enhance understanding of reverse logistics and product life cycle. Additionally, future research should focus on reducing medical waste and its impact on sustainability. The medical supply chain, which primarily involves product and service flow, should also be explored for information and financial flows.

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Brian J. Hiatt earned his Doctorate in Logistics and Supply Chain Management from the University of North Texas in 2023. Dr. Hiatt research interest includes the medical supply chain, human organ transplant logistics, drone and autonomous vehicles, and supply chain resilience. Dr. Hiatt currently teaches, the introduction to logistics and supply management course to undergraduate students as an Adjunct Professor. Dr. Hiatt is also working full time at McKesson Corporation as a Compliance and Monitoring specialist. Prior to his current roles, Dr. Hiatt spent 8 years serving the United Sates Army as a Logistics Officer. During his time in the Army, he served as Company Commander of a forward support logistic company. He oversaw the day-to-day feeding, maintenance, fueling and transportation support for 5 armored cavalry companies consisting of 605 personnel and 230 vehicles. Dr. Hiatt also served as a General's Aide to the senior General in charge of contracts in Afghanistan and Qatar. After his military service Brian worked in a forward distribution center as a Logistics Manager. Dr. Hiatt revived his undergraduate degree in Global Business from Arizona State University. He earned his MBA with a concentration in Logistics from Trident International. Additionally, he was awarded a U.S. patent #US7794272B1 as the co-inventor of the serial bus power cable. Dr. Hiatt is also a certified Six Sigma Black Belt.

Seock-Jin Hong, Ph.D., is an Associate Professor at the University of North Texas (UNT), USA. Before joining UNT, Dr. Hong was a professor at the Kedge Business School in Bordeaux, France, and an associate professor at Incheon National University, Korea. He also held positions as a research associate in the air transport department of the Korea Transport Institute and as a senior researcher at Korean Airlines in Seoul, Korea. Dr. Hong obtained his Ph.D. from the University of Toulouse 1 in France and a Masters in Transport Economics from the Ecole National des Ponts et Chausées in Paris, France. His research interests include air cargo, airports, and supply chain management. His work has been published in journals such as the International Journal of Production Economics, Transportation Policy, the International Journal of Logistics and Management, the Journal of Retailing and Consumer Services, and the Journal of Air Transport Management.

Ik-Whan G. Kwon, Ph.D., is a Professor Emeritus of Supply Chain Management at Saint Louis University. He served as Academic Advisor on MS in Supply Chain Management program. Dr. Kwon is also Founding Director of the Center for Supply Chain Management Excellence since 1988 and currently serves as Director Emeritus since July 2016. He received his BA in Economics from Korea University and first Ph.D. degree in Economics from University of Georgia in 1968. His second

Ph.D. degree in Health Services Research was awarded in 1990 from the School of Public Health, Saint Louis University. In 2002, Dr. Kwon was a Fulbright Scholar to Korea Development Institute School of Public Policy and Management and Yonsei University both in Seoul, Korea. He is also a recipient of the Fulbright Specialist Award in 2009 to Incheon National University School of Logistics. He is a recipient of the National Defense Transportation Association Distinguished Educator Award in 2006 and 2007. He is also recipient of the Chairman's Commendation Award from the United States Consumer Product Safety Commission. He has published over 100 academic articles in various journals in the areas of supply chain management, healthcare supply chain management and humanitarian supply chain management. He is currently on Editorial Board for several journals.

Michael J. Savoie, Ph.D., is a Full Clinical Professor of Operations and Supply Chain Management at the University of North Texas and former Dean of the College of Technology & Computing at Utah Valley University. Dr. Savoie is an internationally recognized public speaker and serves as a consultant to numerous companies and government entities. He has published over 150 books, articles and conference proceedings in Supply Chain Management, Strategic Planning, Cybersecurity, Information Systems and Data Analytics. Dr. Savoie is an Interdisciplinary Fellow of the International Institute of Informatics & Systemics (IIIS).