University of Tehran Press

Industrial Management Journal

Online ISSN: 3115 - 7386

Homepage: https://imj.ut.ac.ir

A Sustainable Healthcare Supply Chain Model Based on Big Data Analytics, Lean Operations, and Integration

Fatemeh Khodabakhshi Parizi [1], **Mojtaba Farrokh**✉ [2], **and Mohammad Mehrabioun** [3]

1. MSc, Department of Operations Management and Information Technology, Faculty of Management, Kharazmi University, Tehran, Iran. E-mail: Fatemeh.kh.parizi@gmail.com
2. Corresponding author, Assistant Prof., Department of Operations Management and Information Technology, Faculty of Management, Kharazmi University, Tehran, Iran. E-mail: Farrokh@khu.ac.ir
3. Assistant Prof., Department of Operations Management and Information Technology, Faculty of Management, Kharazmi University, Tehran, Iran. E-mail: Mehrabioun@khu.ac.ir

Article Info

Article type:
Research Article

Article history:
Received January 03, 2025
Received in revised form July 07, 2025
Accepted July 15, 2025
Available online September 15, 2025

Keywords:
Big data analytics, healthcare supply chain, lean management, sustainable performance, and supply chain integration.

ABSTRACT

Objective: In recent years, big data analytics (BDA) technologies have garnered increasing attention from researchers. However, limited empirical research has explored the benefits of BDA in supply chain integration and lean operations and its influence on sustainable performance in the healthcare sector. To address this gap, the research aims to design and present a conceptual model to investigate the relationships among supply chain integration, lean operations, sustainable supply chain performance, and BDA capabilities.

Methods: This research adopts a survey-based approach, using an online questionnaire to collect data from 104 public and private hospitals in Iran. Data analysis was conducted using structural equation modeling (SEM) via the Partial Least Squares Method (PLS-SEM).

Results: The results revealed that BDA capabilities directly improve sustainable supply chain performance. Moreover, lean operations and supply chain integration mediate between BDA capabilities and sustainable performance. It was also found that BDA capabilities enhance both lean operations and supply chain integration, with supply chain integration directly impacting lean operations. These findings suggest that BDA capabilities can be leveraged as a key enabler to strengthen lean operations, improve supply chain integration, and achieve sustainable supply chain performance.

Conclusion: While some literature has addressed various aspects of supply chain digitalization, no prior research has specifically examined the potential impacts of BDA on sustainable and lean supply chain performance within the healthcare sector. The results offer meaningful contributions for academic researchers interested in the topic, business professionals specializing in digital supply chain management and sustainable operations, healthcare organizations, and any stakeholders seeking to better understand the influence of BDA on sustainable operations and overall business performance.

Cite this article: Khodabakhshi parizi, F., Farrokh, M., & Mehrabioun, M., (2025). A sustainable healthcare supply chain model based on big data analytics, lean operations, and integration. ***Industrial Management Journal***, 17(3), 56-89. https://doi.org/10.22059/imj.2025.388084.1008218

Publisher: University of Tehran Press.

DOI: https://doi.org/10.22059/imj.2025.388084.1008218

Introduction

The healthcare sector, driven by social pressures, customer concerns, and regulatory requirements, urgently needs to enhance its sustainability dimensions (Duque-Uribe et al., 2019). Sustainable performance in this sector involves improving the quality of healthcare services, increasing resource efficiency, reducing environmental pollutants, and enhancing patient satisfaction. With the rapid growth in the volume of healthcare data, BDA has emerged as a comprehensive and more precise approach to managing and improving sustainable performance. BDA capabilities can assist hospitals in achieving both social and economic goals while minimizing environmental impact (Wadmann & Hoeyer, 2018).

The accumulation of data has driven many organizations to develop and deploy BDA tools that transform raw data into actionable insights that enhance decision-making and support the sustainable performance of supply chains (Papadopoulos et al., 2017; Novicka, 2025). Garrison (2013) argues that big data can improve population health and support better policy-making decisions. McKinsey estimates that BDA could save over $300 billion annually in U.S. hospitals, with two-thirds of the savings coming from an approximately 8% reduction in national healthcare expenditures.

Despite these promising figures, the healthcare sector still lacks a clear understanding of how BDA influences the sustainable performance of its supply chains. Moreover, the impact of BDA on sustainability outcomes in healthcare remains underexplored and calls for further empirical investigation. Prior research has reported positive effects of BDA capabilities on sustainable supply chain performance, particularly in reducing carbon emissions and energy consumption (Suifan et al., 2019; Singh et al., 2025).

In recent years, lean thinking and philosophy have become dominant approaches within healthcare systems. Lean management focuses on process improvement by eliminating waste, aiming to enhance hospital performance while increasing patient and staff satisfaction (Zhu et al., 2018). Given that the transition of lean practices from manufacturing to service sectors is relatively recent, the research in the healthcare context remains in its early stages. Furthermore, current studies indicate that lean management, as a comprehensive approach encompassing waste reduction techniques, process improvement strategies, and control methods for error prevention, has not yet been thoroughly examined in healthcare settings. Furthermore, with the increasing volume of data generated within the healthcare sector, BDA has the potential to serve as a fundamental tool for enhancing lean operations and improving efficiency. This area warrants further exploration (Narayanamurthy & Gurumurthy, 2018). In parallel, supply chain integration in healthcare is critical, as it involves improving coordination and collaboration across all stages of procuring medical supplies, equipment, pharmaceuticals, and other essential resources required to deliver high-quality healthcare services. Effective supply chain integration can reduce costs, improve care quality, and increase patient satisfaction.

Recent studies suggest that data-driven approaches, particularly those utilizing big data, can support the implementation of supply chain integration and lean operations (Zhao et al., 2017; Mesquita et al., 2025). Prior research has highlighted the link between BDA and the integration of supply chain processes to enhance organizational performance. This integration typically comprises two dimensions: inter-organizational (external) integration, which relies on the collaboration capacity among supply chain partners (Gunasekaran et al., 2017; Assaad & Sadek Kanaan, 2025), and intra-organizational (internal) integration, aimed at improving effective decision-making processes. The significance of this issue stems from the fact that a lack of integration within the supply chain can negatively impact performance outcomes. Although research exploring the influence of big data on supply chain processes remains in its early stages (e.g., Dubey et al., 2019), the combined effect of the three mechanisms—BDA, supply chain integration, and lean operations—on sustainable performance in the healthcare context has yet to be comprehensively examined. The present study is the first to investigate this relationship within the healthcare supply chain, contributing to a deeper understanding of the mechanisms through which BDA technologies, mediated by lean operations and supply chain integration, influence sustainable performance.

Literature Background

The Role of BDA in the Healthcare Supply Chain

With the rapid expansion of information technology, big data has gained strategic significance and has become one of the most valuable assets for many organizations (Dubey et al., 2019). Big data refers to large-scale, heterogeneous sets of information characterized by high volume, variety, velocity, and veracity. These data can be utilized to uncover patterns, analyze trends, identify hidden relationships, generate data visualizations, and perform predictive analytics across various domains. Technological advancements have increasingly positioned big data as critical in organizational decision-making processes. BDA employs advanced tools and techniques to enable the collection, processing, and analysis of vast and diverse datasets. It is “a new generation of technologies and architectures designed to economically extract value from large volumes of a wide variety of data by enabling high-velocity capture, discovery, and analysis” (Kuo et al., 2014).

Applying these innovative technologies in information processing empowers organizations to develop deeper insights, make more informed decisions, and gain competitive advantages in supply chain management. BDA can transform healthcare by supporting efficient resource utilization, enhancing patient care, and enabling more agile and responsive supply chain operations (Gunasekaran et al., 2017). As healthcare systems face increasing complexity and data proliferation, leveraging BDA has become a strategic necessity for achieving operational excellence and sustainable performance.

To effectively access and capitalize on big data, technologies such as smartphones, RFID, cloud computing, and the Internet of Things (IoT) play a critical role in integrating, processing, and analyzing real-time data. Handling such diverse and rapidly generated data requires innovative and scalable technological infrastructures. Platforms such as Apache Hadoop, Storm, S4, and Dremel enhance organizations' processing capabilities and improve their efficiency in managing big data (Wang et al., 2018). Today, big data is increasingly viewed as a cost-effective approach for conducting large-scale analytics and decision-making in healthcare supply chains. The growing use of telehealth services, the expansion of patient data storage capacities, and the innovative application of technologies such as Google Glass by physicians contribute to big data's social and behavioral dimensions. Electronic Health Records (EHRs), which contain vast amounts of information including patient demographics, clinical data, and genomic profiles, play a pivotal role in supporting health-related activities. Moreover, data about raw materials and pharmaceuticals are generated throughout the healthcare supply chain via IoT and cloud computing technologies. These data sources are often analyzed using data analytics techniques to derive actionable insights (Kuo et al., 2014). Healthcare-related big data empowers tasks that were previously unattainable—such as identifying key health trends, closely monitoring infectious diseases to control outbreaks, forecasting inventory needs to reduce costs, and enabling patients to take greater control of their health to improve public health outcomes and reduce social disparities (Kuo et al., 2015). The analysis of this vast volume of data offers physicians, healthcare providers, suppliers, policymakers, and patients the opportunity to reduce the time and cost associated with information search and processing. Simultaneously, it supports achieving sustainable performance by leveraging the capabilities of BDA. Furthermore, big data unlocks new capacities within the supply chain by providing opportunities to measure supplier performance, conduct efficient supply chain analytics, and enhance agility, sustainability, and innovation across the supply chain (Raghupathi & Raghupathi, 2014).

Despite its advantages, big data also presents significant challenges. Data privacy and security are among the most pressing concerns, particularly in sensitive sectors such as healthcare. The confidential nature of health-related information necessitates stringent data protection measures. These challenges require aligning technologies with recognized security standards and developing human capabilities to manage the technical dimensions of BDA (Kache & Seuring, 2017; Tambuskar et al., 2024).

Previous studies have emphasized that the effectiveness of BDA in complex supply chains such as those in healthcare is contingent upon addressing technical and organizational barriers (Moyano-Fuentes & Sacristán-Díaz, 2012; Flynn et al., 2010). Issues such as lack of interoperability, fragmented systems, and inadequate data governance can hinder data-driven decision-making (Castillo et al., 2018). Moreover, ensuring ethical data handling practices and maintaining stakeholder trust are critical, especially when integrating multiple structured and unstructured data sources across the supply chain (Davidson et al., 2017). In addition, successful deployment of BDA requires advanced analytical competencies, cross-functional collaboration, and strategic alignment between IT capabilities and organizational goals (Chen et al., 2013). Risk awareness, proactive data integrity, and quality management are equally important to ensure reliable insights (Drupsteen et al., 2013). As Dobrzykowski and Tarafdar (2015) suggest, overcoming these challenges is essential for optimizing healthcare supply chains and achieving sustainable performance through the responsible and effective use of BDA.

Healthcare Supply Chain Integration

Effective supply chain management requires integrating internal business processes and coordinating with external suppliers and customers. In this context, supply chain integration refers to strategic activities through which a focal company collaborates with its supply chain partners to jointly manage internal and external processes to achieve desirable performance outcomes (Moyano-Fuentes & Sacristán-Díaz, 2012). An integrated supply chain aims to enable efficient and effective flows of products, services, information, finances, and decisions to deliver maximum value to customers at low cost and high speed (Flynn et al., 2010).

The advantages of supply chain integration have been confirmed by numerous studies, which highlight its contribution to enhanced performance, sustainable development (Castillo et al., 2018), and improved product quality (Davidson et al., 2017). Within healthcare supply chains, integration has also improved the flow of information, materials, and patients (Chen et al., 2013; Drupsteen et al., 2013). Healthcare supply chain processes are characterized by complex flows of information, physical goods, and financial resources, necessitating tight coordination and integration across organizational boundaries and among diverse stakeholders (Dobrzykowski & Tarafdar, 2015). This study extends the traditional concept of supply chain integration—initially focused primarily on the manufacturing sector (Flynn et al., 2010; De Vries & Huijsman, 2011)—to the context of healthcare supply chains. It does so by considering how joint management of intra-organizational and inter-organizational processes can lead to more efficient flows of patients, information, and medical materials. Accordingly, in this research, healthcare supply chain integration is conceptualized as a multidimensional construct that includes intra-organizational integration, hospital–patient integration, and hospital–supplier integration.

Dimensions of Healthcare Supply Chain Integration

Based on previous studies in the manufacturing sector (e.g., Flynn et al., 2010; Wong et al., 2011), intra-organizational integration within the supply chain is defined as part of a cohesive process involving interaction, information sharing, and collaboration among various functional units of an organization (Drupsteen et al., 2016). Establishing coordination across departments in healthcare and hospital settings is critical, as effective service delivery depends on the harmonious collaboration of different hospital functions such as patient scheduling, daily monitoring, and performance management (Drupsteen et al., 2013). This type of integration helps eliminate operational silos and enables the timely and accurate exchange of information between key units like emergency services, operating rooms, and radiology departments. Ultimately, such coordination leads to better responsiveness to patient needs and improvements in the quality of healthcare services (Flynn et al., 2010). Hospital–patient integration refers to the degree of effective and timely interaction between hospitals and their patients. This relationship requires a deep understanding of patients' needs, preferences, and expectations, enabling hospitals to align supply with demand better and respond more swiftly to patients' evolving requirements (Wong et al., 2011; Dobrzykowski & Tarafdar, 2015). Moreover, this integration relies on the smooth exchange of information such as medical histories, lab results, and prescriptions, contributing to enhanced clinical care quality and more efficient bedside outcomes (Dobrzykowski & Tarafdar, 2015).

Hospital–supplier integration denotes strategic alignment and coordination between hospitals and key suppliers. This integration involves logistical coordination, information and resource sharing, and ensures a reliable, timely, and adequate supply of medical equipment and materials (Alshahrani et al., 2018; Chen et al., 2013). Higher levels of integration are associated with improved communication quality, better logistical coordination, more efficient distribution of medical supplies, and seamless replenishment processes—all of which ultimately enhance overall hospital performance (Chen & Paulraj, 2004; Nyaga et al., 2015).

Lean Healthcare Operations

The lean paradigm refers to activities or solutions to eliminate waste, reduce non-value-added activities, and focus on value-adding processes (Narayanamurthy & Gurumurthy, 2018). Typical forms of waste include overproduction, waiting time, transportation, overprocessing, excess inventory, unnecessary movement, and faults (defects). The lean approach seeks to optimize value-added and non-value-added activities to significantly impact productivity, cost, and quality. Lean operations are a multifaceted concept encompassing a range of internal and external organizational functions. These include just-in-time production, total quality management, preventive maintenance, pull systems, quick setup times, controlled processes, and employee involvement (Yang et al., 2011). Typically, lean operations eliminate waste, improve quality, and reduce product or service delivery times. Removing these inefficiencies can enhance hospitals' capacity to meet growing demand for medical treatments (Narayanamurthy & Gurumurthy, 2018).

However, applying lean concepts in service sectors such as healthcare requires adaptation to the specific requirements of that field. For instance, the seven types of production waste identified by Ohno were extended to the hospital setting by Bicheno and Holweg (2008). In this context, inventory waste in healthcare can be defined as the number of units in process within a care delivery system, including medical supplies, inventory items, and patient waitlists. Given the potential for improvement, lean operations in hospitals have gained considerable attention. One approach to addressing current challenges in this sector is through lean processes and achieving operational savings. Although healthcare differs from manufacturing in many ways, there are also similarities. Lean thinking in hospitals can positively impact productivity, cost, quality, and timeliness of service delivery (Castaldi et al., 2016).

Research at the Georgia Institute of Technology indicated that 40% of healthcare costs are non-value-added (Régis et al., 2019). These wastes include unnecessary procedures, incorrect medications, delays in treatment, misdiagnoses, noncompliance with best practices, communication failures and related chaos, long wait times for materials, equipment repairs, staffing issues, suboptimal material conditions, disorganized workplaces, poorly structured processes, high energy consumption, excessive inventories, and lack of expiration monitoring for drugs and medical supplies. Additionally, De Souza (2009) reported that the use of lean thinking in hospitals began in the UK in 2001 and resulted in a 42% reduction in paperwork, a 38% reduction in patient visit time, a 33% reduction in overall patient length of stay, and a 36% reduction in mortality rates. Moreover, lean initiatives at the Scottish Cancer Treatment Centre improved patient flow time by up to 48% and reduced the average appointment wait time from 23 to 12 days. These studies demonstrate that adopting a lean operations approach in healthcare can significantly reduce costs, improve processes, and ultimately enhance patient service delivery. Therefore, focusing on implementing lean methods in hospitals can improve the overall performance of the healthcare sector.

Sustainable Performance in Healthcare Supply Chains

According to the World Commission on Environment and Development in Europe, sustainability refers to development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Wadman & Huyer, 2018). A literature review shows that the definition of sustainability can range from an internal organizational philosophy to a multidimensional focus including economic, social, and environmental sustainability. The internal organizational philosophy emphasizes ensuring that future generations do not suffer from problems or negative impacts caused by today's activities (Farhadi et al., 2018). The multidimensional focus stresses balancing the social, economic, and environmental aspects. In social sustainability, it is essential to ensure that services effectively meet community needs. Environmental sustainability aims to reduce the consumption of nonrenewable resources and optimize resource use to prevent waste production and environmental harm. Economic sustainability focuses on planning and optimizing the supply chain to maximize profit; in other words, increasing product value with minimal use of raw materials, inventory, and production costs. Therefore, sustainable performance involves a combination of social, economic, and environmental dimensions (Zhou et al., 2018). Consequently, the sustainable performance of the supply chain should be evaluated not only based on profit but also considering its simultaneous impacts on social, economic, and environmental systems.

Carter and Rogers (2008) defined sustainable supply chain performance as the strategic and transparent integration to achieve an organization's social, environmental, and economic goals through systemic coordination of key inter-organizational business processes, aiming to improve the organization's long-term economic performance. Today, sustainable performance also holds a special position in healthcare supply chains. Among service sectors, healthcare—one of the largest service fields—offers a unique opportunity to impact sustainable performance. On average, the healthcare sector consumes more energy than other service sectors and generates significant amounts of hospital waste. Additionally, due to its high number of employees compared to other service organizations, healthcare has a considerable social impact on society (Zhou et al., 2018).

The supply chain holds a high status in healthcare because it is responsible for preserving public health and caring for lives. However, healthcare supply chains often face social, economic, and environmental challenges. From an economic perspective, rising healthcare costs require services to be delivered more effectively and efficiently. Between 30% and 40% of hospital budgets are allocated to supply chain costs, which can be reduced by up to eight percent by implementing best practices. Environmentally, healthcare processes and services are highly excessive in using materials, energy, and water, producing large amounts of waste and greenhouse gases. Social challenges related to hospital supply chains are also significant. Internally, although hospitals are considered large employers, wages have declined compared to other sectors, and women's salaries are significantly lower than men's (Shahhoseini et al., 2019). Moreover, daily working hours often exceed legal limits, and safety issues are frequently neglected. Job characteristics such as shift work and long hours not only increase the risk of occupational accidents and psychological stress but also negatively affect the quality of patient care. Externally, hospitals have a substantial societal impact because the quality of healthcare services directly affects people’s quality of life (Duque-Uribe et al., 2019).

Research Objectives and Gaps

All researchers agree that lean operations strategies and supply chain integration positively impact improving sustainability performance at the supply chain level (Flynn et al., 2010; Izadyar et al., 2020; Mesquita et al., 2025). A literature review shows these two strategies have typically been studied separately. No study has investigated these two strategies' complementary and synergistic roles on supply chain sustainability.

On the other hand, supply chain integration in the healthcare sector appears to play a central role as a key enabler, supporting core processes in implementing lean supply chain strategies (Novais et al., 2020).

BDA capability enhances supply chain sustainability performance when implemented within organizational processes (Benzidia et al., 2024; Tetteh et al., 2025). Some studies have emphasized the importance of BDA capabilities and data-driven decision-making actions in enhancing sustainable performance (Singh et al., 2025; Novicka, 2025).

Moreover, besides supporting lean operations and supply chain integration strategies, BDA capability acts as a complementary and synergistic strategic initiative, offering competitive advantages to firms. Therefore, BDA capability has the potential to facilitate the development of lean principles and practices across the supply chain and integrate them at unprecedented levels (Fayyaz et al., 2024; Mesquita et al., 2025; Assaad & Sadiq-Kanaan, 2025). Moreover, equipping supply chains with big data infrastructure facilitates implementing lean operations and supply chain integration strategies. This enables higher levels of flexibility and automation in processes and enhanced attention to environmental and social issues within the healthcare sector. Ultimately, this leads to improved sustainability performance across the supply chain (Mesquita et al., 2025).

According to recent literature, researchers have emphasized the role of various digital technologies, such as BDA capability, cloud computing, blockchain technology, the IoT, and artificial intelligence, in connecting the supply chain through real-time flows of physical, informational, and financial resources (Assaad & Sadiq-Kanaan, 2025). These technologies are key resources because they support implementing lean practices and supply chain integration (Fayyaz et al., 2024; Mesquita et al., 2025).

So far, initial efforts have primarily focused on internally combining BDA capabilities and lean manufacturing methods. However, the role of BDA in enabling lean practices has not yet been explored from a supply chain and strategic perspective. Furthermore, previous research indicates that BDA capabilities and other digital technologies influence lean operations and supply chain integration. Nonetheless, many of these studies have analyzed the effect of digital technologies on lean operations and supply chain integration separately.

In addition, the results in the literature regarding the relationship between digital technology resources and sustainable supply chain performance have been inconsistent. While some studies show that digital technologies impact sustainable supply chain performance (Singh et al., 2025; Mesquita et al., 2025), others argue that this impact is only realized when combined synergistically with other supply chain strategies (Putnik & Putnik, 2012). Therefore, empirical research is needed to clarify how various digital technology resources—such as BDA—can be integrated with lean operations and supply chain integration strategies.

Additionally, although some earlier studies have examined the outcomes of lean supply chain strategies and supply chain integration on firm sustainability performance, investigating the mediating role of these strategies in the relationship between BDA and sustainable supply chains can offer complementary insights to explain these conflicting findings. To address these gaps, the current study aims to enhance understanding of the mediating role of lean operations and supply chain integration in the effect of BDA on sustainable supply chains in the healthcare sector. Accordingly, this study is the first to examine the impact of lean operations and supply chain integration—enabled by BDA capability—on sustainable supply chain performance. As a result, this study aims to fill this gap and provide a framework for healthcare managers, enabling them to enhance sustainability performance by implementing BDA capability, strengthening lean operations strategies, and supply chain integration.

Conceptual Framework and Hypotheses

The impact of BDA capabilities on sustainable supply chain performance (SSCP) has been widely discussed in previous literature. The application of BDA has significantly contributed to economic, social, ethical, legal, and political benefits in Europe, with potential applicability in other regions (Jeble et al., 2018).

Findings further suggest that BDA simplifies supply chain operations and supports developing a sustainable system (Shokouhyar et al., 2020; Belhadi et al., 2020). BDA also facilitates the analysis of the impacts of sustainable supply chain management (SSCM) and provides more accurate assessments of environmental effects. A data-driven, sustainable supply chain supports achieving economic goals through cost savings, improved coordination, and enhanced collaboration among various stakeholders across the supply chain.

Moreover, decision support systems in a BDA environment are essential for maximizing resource utilization, allowing organizations to operate more efficiently while meeting sustainability objectives (Belhadi et al., 2020). Furthermore, they found that BDA plays a significant role in enhancing sustainable supply chain performance.

Similarly, Bag et al. (2020) examined the role of BDA in developing sustainable supply chain performance. They discovered that the managerial capabilities of BDA teams positively influence green products, innovation, and the benefits of a sustainable supply chain.

These findings highlight that beyond just technological capability, managerial competence in utilizing big data plays a crucial role in driving sustainability, innovation, and environmental responsibility within the supply chain.

BDA is recognized as a critical capability for monitoring and tracking social aspects. Kuo et al. (2014) demonstrated that companies can effectively use BDA to manage information and insights gathered from online social networks. This allows them to provide more adaptive and focused responses to various stakeholders or issues—ultimately creating more value for society. According to Khan et al. (2021), organizations can leverage BDA techniques to unlock, model, and predict social stakeholders' behaviors, enabling the identification of emerging trends and potential social concerns. This process also helps promote collective solutions for diverse stakeholders, enabling them to adopt collaborative and transformative options to address these issues.

Based on this, the following hypothesis can be proposed:

H1: BDA capabilities directly and positively impact the sustainable performance of the healthcare supply chain.

The volume and velocity of data and real-time analytics enabled by BDA can significantly reduce service delivery time, enhance coordination across supply chain activities, improve communication among supply chain components, manage inventory between manufacturers and suppliers, and forecast customer demand. Timely information allows organizations to act faster than their competitors. Additionally, BDA capabilities can positively influence lean operations strategies.

Although examples of BDA capability development to support lean operations are rare, among the limited studies available, the impact of BDA on lean operations has been confirmed (Belhadi et al., 2020). Furthermore, existing literature emphasizes that decision-making efficiency improves when lean operations initiatives are integrated with BDA capabilities (Demirdöğen et al., 2020). BDA capabilities help develop models of internal processes, leading to standardization and waste reduction. Moreover, BDA enhances process efficiency and provides technical and organizational flexibility, helping organizations identify and address inefficiencies. Based on these findings, the following hypothesis can be considered:

H2: BDA capabilities directly and positively impact lean operations in the healthcare sector.

Several scholars have emphasized the importance of BDA capabilities in internal and external supply chain integration (Yu et al., 2021; Benzidia et al., 2021). These capabilities enable organizations to effectively and rapidly combine and process different data types, equipping them with the tools to manage variability and uncertainty. As a result, organizations can achieve effective supply chain integration (Srinivasan & Swink, 2018). Hospitals' ability to collect, analyze, and process massive amounts of healthcare-related data (including electronic health records, diagnostic or monitoring device data, pharmacy data, and patient-generated data) allows them to break down functional silos and operate cohesively to improve efficiency and coordination (Wang et al., 2018). In addition, BDA helps hospitals process unstructured data (such as medical records, doctors' and nurses' notes, prescriptions, and CT images) and convert them into a structured and analyzable format that can be effectively shared across different departments (Raghupathi & Raghupathi, 2014). Adopting BDA technologies facilitates information exchange between doctors and patients, enhancing hospital–patient integration.

BDA capability development enables hospitals to analyze and process real-time medical data collected from various mobile devices (e.g., mobile health apps, sensors, medical devices, and remote monitoring systems) to assess and track patient health status for diagnosis, prescription, and treatment (Raghupathi & Raghupathi, 2014; Wang et al., 2018). These capabilities help hospitals and healthcare providers effectively communicate with patients to achieve better healthcare outcomes (Dobrzykowski & Tarafdar, 2015). Moreover, collecting and processing managerial and clinical data provides meaningful insights that assist hospitals and their suppliers in monitoring, controlling, and optimizing inventory levels (Chen et al., 2013) and collaborating to respond to patient demands and future market trends (Wang et al., 2018). Hospitals that invest in developing analytical capabilities (analyzing and processing business data related to inventory, production planning, capacity, and delivery scheduling) are more likely to consistently align and collaborate with key suppliers for planning, fulfilling, and delivering hospital materials and equipment (Chen et al., 2013). For instance, Assaad and Sadiq Kanaan (2025) demonstrate that integrating big data and AI significantly enhances knowledge sharing and supply chain integration. In this context, the development of BDA has become an essential factor for improving hospital–supplier integration. Given the significant benefits of these capabilities, it is expected that BDA will enable hospitals to improve internal integration across departments and strengthen strategic collaboration with patients and suppliers. Therefore, the following hypothesis may be proposed:

H3: BDA capabilities directly and positively affect healthcare supply chain integration.

According to the literature, the efficiency of lean production practices in the supply chain depends on the company's integrated relationship with its suppliers and customers (Novais et al., 2020). On the other hand, customer satisfaction and long-term relationships with suppliers are essential for a lean system. Hence, some companies involve customers and suppliers as external factors to improve lean operations (Moyano-Fuentes & Sacristán-Díaz, 2012). Utilizing both factors simultaneously creates value for the organization and can become a competitive advantage in the market. Therefore, the following hypothesis can be examined:

H4: Healthcare supply chain integration significantly and positively affects lean operations.

Lean and sustainable approaches can complement each other, but must be implemented using different approaches. Lean operations begin at the operational level and can be implemented from bottom-up or mid-level to top-level. In contrast, sustainable performance must be adopted and implemented through top-down organizational strategies. The literature review shows that studies on the effects of lean operations on sustainable supply chain performance, especially in the long term, are still insufficient.

Sajan and Shalij (2021) evaluated various connections between lean operations and sustainable supply chain performance. According to Castillo et al. (2018), lean operations are recognized as an effective driver for improving efficiency, and their significant impacts on environmental and social sustainability can also lead to reduced economic costs. The study by Bergenwall et al. (2012) is perhaps the most comprehensive research to date on the relationship between lean operations and sustainability from the perspective of the triple bottom line (economic, environmental, and social dimensions of sustainability). Their findings show that overproduction and harmful environmental effects result from a mismatch between pull and push inventory systems, leading to excess inventory. Moreover, concerns about increased air pollution due to the need for frequent transportation under just-in-time production practices were raised.

Zhou et al. (2018) conducted a case study on several companies in various manufacturing sectors. Their findings confirmed a significant positive relationship between lean production and sustainability. However, they also observed negative relationships between lean production and environmental performance, particularly among companies lacking a clear sustainability strategy. Their findings somewhat differ from the results of Sajan and Shalij (2021), who confirmed significant positive effects of lean operations on all three dimensions of sustainable performance. Interestingly, in their study, the observed relationship between lean production and environmental performance was stronger and more prominent than the relationship with the economic and social dimensions. However, they did not explain these findings.

The results of the study by Izadyar et al. (2020) also showed that improvement scenarios in implementing total quality management (TQM), just-in-time (JIT) production, and flexible transportation lead to a more sustainable supply chain. Overall, it must be acknowledged that the effects of lean operations on the three dimensions of sustainable performance are inherently complex. One source of this complexity is the lack of precise criteria for measuring each sustainability dimension. Therefore, the following hypothesis can be proposed:

H5: Lean operations directly and positively affect sustainable healthcare supply chain performance.

Reviewing previous studies suggests that supply chain integration impacts companies' sustainable performance. For instance, the findings of some studies (Flynn et al., 2010) show that the highest degree of supply chain integration—both internal and external—leads to the highest level of sustainable performance. In other words, the greater the supply chain integration, the higher the level of sustainable performance achieved.

On the other hand, some studies have taken a more detailed look at the various dimensions of integration and sustainable performance, examining the relationships between specific aspects of each separately. These studies show that certain dimensions of supply chain integration directly and positively affect specific aspects of sustainable performance (Flynn et al., 2010). Supply chain integration can offer benefits such as reduced inventory and total cost, improved information sharing, increased profitability and service levels, innovation in technology and product design, and ultimately, enhanced operational and financial performance of supply chain partners, leading to improved sustainability performance. Therefore, the following hypothesis can be proposed:

H6: Healthcare supply chain integration directly and positively affects sustainable performance.

BDA capabilities enable organizations to identify hidden patterns and trends through comprehensive data analysis. These analytics assist in strategic decision-making, optimize lean operations, and facilitate improved sustainable performance. BDA can also help organizations predict market changes and customer needs, supporting the design of more flexible lean operations that can adapt to rapid changes—ultimately positively impacting sustainable performance (Belhadi et al., 2020). Thus, a meaningful relationship between BDA capabilities, lean operations, and sustainable performance may exist, and investigating this relationship could lead to improved management practices and organizational efficiency. For example, Fayyaz et al. (2024) demonstrate that Green Lean Six Sigma and sustainable supply chain management partially mediate the relationship between BDA and sustainability performance.

Mesquita et al. (2025) emphasize the mediating role of social and technical lean practices in the relationship between BDA capabilities and economic, social, and environmental performance. Meanwhile, an extensive multi-phase study conducted by Benzidia et al. (2021) shows that BDA affects sustainable performance by improving demand forecasting accuracy, a key aspect of supply chain integration.

Therefore, the following hypotheses can be proposed:

H7: BDA capabilities significantly affect sustainable performance through lean operations.
H8: BDA capabilities significantly affect sustainable performance through healthcare supply chain integration.

Based on the above hypotheses, the following conceptual model is illustrated.

Figure 1 presents a reflective measurement model, in which latent variables are the primary factors determining the values of observable indicators. In this model, the fundamental assumption is that the indicators directly reflect the latent constructs—that is, any change in a latent variable systematically leads to proportional changes in all its corresponding indicators (Hair et al., 2011).

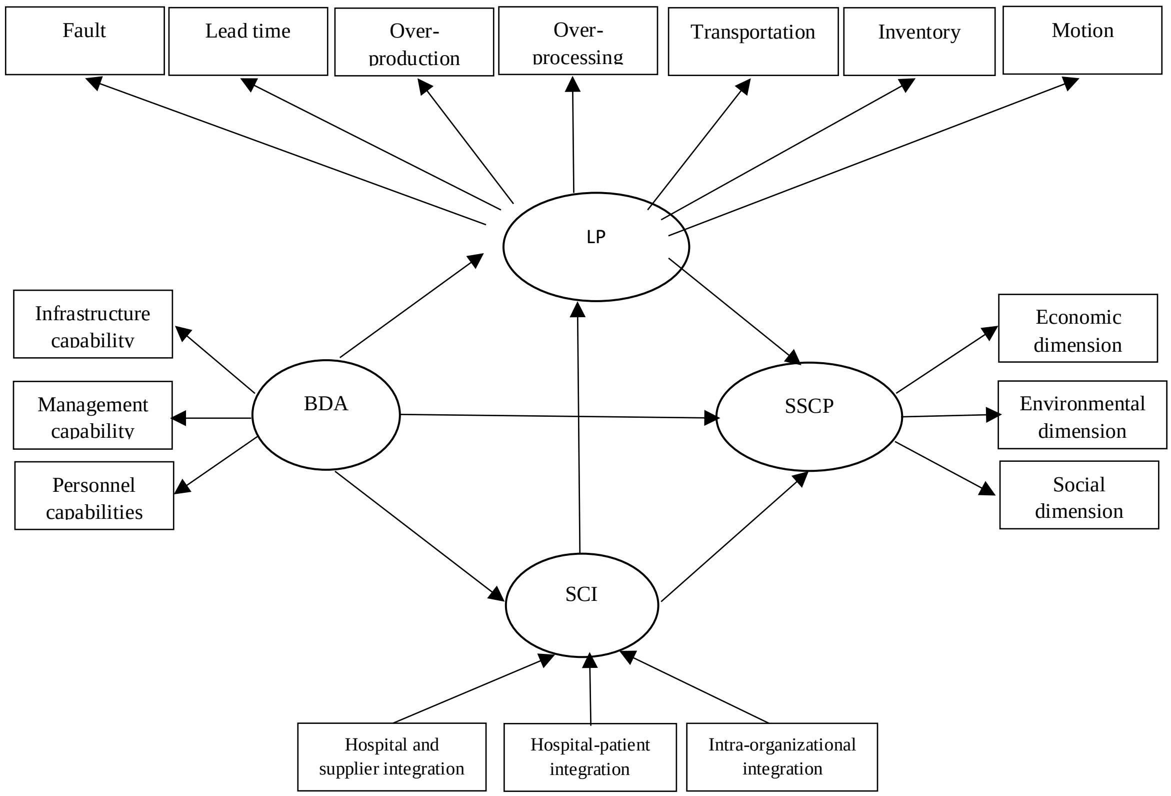

Figure 1. Conceptual Model of the Research

For example, in **Figure 1**, the construct **"Lean Production"** is measured through a set of indicators such as **"Transportation," "Inventory,"** and **"Motion."** These indicators are considered **outcomes of the overall performance of lean operations** and, therefore, theoretically and statistically aligned to reflect the latent variable. Similarly, the "Sustainable Supply Chain Performance" construct is operationalized through economic, environmental, and social performance dimensions. Each represents an aspect of sustainability in the supply chain and is expected to vary in response to changes in the central latent construct.

Materials and Methods

A conceptual model was designed and evaluated using an empirical survey to investigate the relationships and complementarities among the variables. Several prior studies were utilized to operationalize the constructs of the conceptual model. All constructs used within the theoretical framework of the research were operationalized as reflective constructs. The data collection tool comprised four questionnaires to assess the study's constructs. The questionnaire items, which were adapted from various sources, included 75 questions (items), as shown in Table 2.

Sampling and Data Collection

The hypotheses of the conceptual model were tested using the questionnaire. A pre-test of the questionnaire was conducted with seven experts in logistics and supply chain management in the healthcare sector. In addition, four other experts in healthcare supply chain and technology management were consulted to confirm the content validity of the questionnaires. Their suggestions were incorporated into the final survey. Respondents were provided with a glossary of key study terms to avoid confusion in understanding the questions. They were assured that their identities would remain confidential.

Several steps were followed to develop the measurement scale, including a pre-test (Chen & Paulraj, 2004). Initially, the content validity of the measurement scale was ensured. Content validity tests examined whether the various questionnaire items adequately represented the studied phenomenon. To this end, academic literature was reviewed to guide the development of the questionnaire and measurement scales of the model variables before execution. At the end of the literature review, the initial questionnaire version was reviewed and revised by experts who had conducted research in healthcare supply chain and technology management to confirm the content validity of the measures.

Subsequently, the questionnaire was sent to seven experienced hospital logistics and supply chain management experts. These experts assessed whether the scales covered the studied constructs and provided feedback on the scales' structure, wording, and clarity. Their feedback was incorporated into the final questionnaires. The G*Power software version 3.1 was used to determine the required sample size. This calculation aimed to ensure statistical data adequacy for structural equation modeling analysis with a partial least squares approach. The main parameters used in this analysis included a significance level of 0.05, statistical power of 0.80, and a medium effect size (0.2). The number of predictor variables was considered to be 8, because within the endogenous constructs of the conceptual model, the construct “Lean Operations” had the largest number of direct predictor variables. This construct was directly influenced by eight components, including various types of waste (such as motion, transportation, inventory, over-production, over-processing, waiting time, and fault) and BDA. Based on these settings, the G*Power output suggested a minimum sample size of 95 participants to achieve the desired statistical power.

Table 1. Evaluation of measurement model reliability and validity

Variable	Cronbach's alpha	Composite reliability	AVE	Items	Cronbach's alpha	Composite reliability	AVE
Big Data Analytics (BDA) (Jeble et al., 2018)	0.889	0.912	0.829	Infrastructural capability	0.832	0.821	0.672
				Managerial capability	0.834	0.902	0.751
				Personnel capability	0.831	0.899	0.748
Supply Chain Integration (SCI) (Dobrzykowski & Tarafdar, 2015)	0.899	0.883	0.695	Hospital and patient integration	0.834	0.902	0.751
				Intra-organizational integration	0.834	0.902	0.755
				Hospital and suppliers integration	0.781	0.86	0.693
Lean Production (LO) (Bicheno & Holweg, 2008; Demirdöğen et al., 2020)	0.789	0.802	0.846	Inventory	0.942	0.958	0.852
				Transportation	0.812	0.816	0.619
				Over-processing	0.872	0.888	0.812
				Lead time	0.813	0.812	0.598
				Over-production	0.844	0.892	0.741
				Fault	0.81	0.873	0.723
				Motion	0.802	0.797	0.586
Sustainable Supply Chain Performance (SSCP) (Wadmann & Hoeyer, 2018; Duque-Uribe et al., 2019)	0.821	0.795	0.723	Economic	0.727	0.879	0.785
				Environmental	0.792	0.861	0.703
				Social	0.771	0.841	0.687

The online questionnaires were distributed in public and private hospitals across Iran and returned via email. Out of 220 surveys distributed, 117 completed questionnaires were received. Thirteen surveys were discarded due to incomplete responses; therefore, the final sample size was 104, reflecting a response rate of 47%. This sample size exceeded the minimum threshold determined by G*Power and was adequate for conducting structural equation modeling analysis.

Results

WarpPLS 5.0 software was used in this study based on the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach (Kock, 2019). PLS-SEM was selected as a predictive approach for estimating the research model because it is helpful for theory development in complex and exploratory models. Additionally, this method is more appropriate for small sample sizes with fewer than 250 observations. The model estimation was carried out in two stages according to recommendations in the literature (Moshtari, 2016). First, the reliability and validity of the measurement model were assessed. Then, the structural model with reflective constructs was analyzed.

Measurement Model Evaluation

This section further evaluates the reliability, discriminant, and convergent validity of all constructs in the theoretical model. Convergent validity is assessed to determine whether different items effectively measure the same conceptual dimension, following the guidelines of Fornell and Larcker (1981). For this purpose, criteria such as factor loadings of the items, composite reliability (CR), and average variance extracted (AVE) are used. As shown in Table 2, all factor loadings exceed 0.5 and are statistically significant at the 1% level (Kline, 1998). Table 1 shows that the composite reliability for each construct is above the acceptable threshold of 0.7, indicating acceptable internal consistency (Bagozzi et al., 1988). Moreover, AVE values for all constructs are greater than 0.5, which means each construct explains more than 50% of the variance of its indicators (Hair et al., 2019). Additionally, all Cronbach’s alpha values are above the minimum threshold of 0.7, confirming the reliability and validity of the variables. Finally, discriminant validity was assessed using two different approaches. First, the Fornell and Larcker (1981) criterion was applied, requiring the correlations between constructs to be lower than the square root of each construct's average variance extracted (AVE).

Table 2. Standard coefficients and significance levels of items

Dimensions	Items	Factor loading	Significance
Infrastructural capability	In the hospital, data from multiple sources is used to improve decision-making.	0.802	31/24
	The hospital has an organized network within its various departments to share data or information effectively in an integrated system.	0.835	00/10
	Information is shared across the hospital from different locations and positions.	0.949	96/42
	The hospital's information system comprises functional partitioning into scalable and reusable modules.	0.766	18/36
	The hospital continuously seeks new opportunities to utilize data analytics.	0.746	21/52
Managerial capability	The hospital systematically pursues appropriate programs to strengthen its information system.	0.843	926/40
	The hospital continuously updates its analytics programs according to new conditions.	0.790	755/18
	Sufficient resources are allocated for the development and implementation of BDA.	0.924	183/20
	The hospital has identified the impact of BDA on lean management, integration, and sustainability, and supports a preventive approach to address related challenges.	0.806	990/5
	It also assesses its impact on social welfare (protecting human rights, ensuring the organization does not participate in human	0.869	264/17

Industrial Management Journal, Volume 17, Issue 3, 2025

	rights violations, and eliminating all forms of forced labor and discrimination related to employment).		
	The data analysis department broadly shares integrated information with strategic decision-makers.	0.904	025/9
	Compared to other hospitals, your hospital's BDA department performs better in providing and sharing accurate information effectively.	0.975	241/30
	Unlike other hospitals, the BDA department effectively shares accurate and timely information.	0.839	152/69
Personnel capabilities	Data analytics personnel are qualified in programming skills such as web-based applications, structured programs, and other related tools.	0.930	630/18
	They are proficient in data mining and statistical analysis software such as Python, R, SPSS Statistics, and SPSS Modeler.	0.751	128/9
	They also possess high skills in decision support systems (like AI, data warehouse, data market, etc.).	0.773	564/12
	Their competencies include distributed computing, data management and maintenance, and project lifecycle management.	0.846	297/37
	They have extensive knowledge of statistics, data mining, IT systems, business intelligence, and related topics.	0.965	923/20
	Data analytics personnel have effective teamwork and communication skills.	0.933	782/11
Hospital and patient integration	The hospital predicts and responds to the evolving needs and desires of patients.	0.927	645/13
	It constantly interacts with patients to improve reliability, responsiveness, and other standards.	0.846	419/26
	It provides services and treatments that meet or exceed patients' expectations.	0.856	915/12
Intra-organizational integration	Staff are brought together to facilitate integration and coordination between departments.	0.771	001/39
	Heads and managers of each department regularly visit patients.	0.935	650/14
	Information about positive and negative patient experiences is freely shared across all departments.	0.746	254/18
	All responsible persons and managers know how everyone in the hospital can contribute to creating patient value.	0.963	68/4
	All functional units work together to resolve problems jointly and comprehensively.	0.970	29/10
Hospital and supplier integration	Logistics activities between the hospital and its main suppliers are well coordinated.	0.921	91/29
	Logistics activities are integrated with key suppliers to reduce costs and improve service levels.	0.830	76/45
	Hospital logistics are well integrated and facilitated by distribution, transportation, and warehousing.	0.896	43/19
	Inbound and outbound logistics are coordinated with suppliers and vendors.	0.797	68/18
	Information and materials flow smoothly between the hospital and supplier/vendor companies.	0.758	96/23
Inventory	Excess inventory of various items is not stored in the warehouse.	0.932	914/34
	Patients have short waiting lists for medical examinations and diagnostic tests.	0.964	256/7
	The process of obtaining tools and supplies is designed so patients do not have to wait for medical examinations and diagnostic tests.	0.865	660/13

Transportation	The hospital space is designed so that staff do not need constant movement to transfer notes and items.	0.850	218/5
	The hospital has a centralized store for items such as medicines and tools.	0.714	284/16
	Medical imaging facilities are located at the central point of the hospital.	0.869	289/6
Over-processing	Patients do not repeatedly recount their medical history during different treatment stages.	0.782	325/4
	Patient information details are not asked for frequently.	0.969	182/15
	Laboratory or X-ray tests are not repeated unnecessarily to ensure accurate diagnosis.	0.935	615/14
Lead time	Patients wait only a short time for admission and document submission.	0.716	120/35
	The waiting time for surgery is minimal.	0.794	449/20
	Patient discharge is carried out quickly.	0.903	914/7
Over-production	Requests for unnecessary tests are rarely made.	0.855	667/3
	Routine inspections within the hospital are only performed when necessary.	0.812	540/11
	The number of staff in shift schedules is appropriate based on the number of patients and their treatment load.	0.937	743/16
Fault	The need to repeat tests due to unclear information occurs rarely.	0.819	208/12
	Re-hospitalization due to unsuccessful treatment or discharge occurs infrequently.	0.825	233/17
	Diagnostic tests are consistently conducted electronically with barcode identification.	0.935	615/14
Motion	Unnecessary movement and relocation of staff and medical personnel are minimal.	0.727	710/32
	Visual cues are used to guide patients.	0.794	312/19
	Basic equipment is available in each examination room.	0.862	125/7
Economic	Suppliers fully deliver medication and medical equipment orders.	0.901	934/28
	Medical equipment and medicines are always available and not in short supply.	0.984	199/5
	Delivery of medicines and equipment is timely, and services are performed quickly.	0.860	463/17
	Accurate identification and tracking of patients, medicines, and equipment inventory are possible.	0.837	239/7
	Patient information and inventory of medicines and equipment are accessible, accurate, and up-to-date.	0.790	355/26
	The time required to prepare workflows is minimal, and work-related waste has been eliminated.	0.796	845/11
	Appropriate measures have been taken to reduce costs, including operational, warehousing, administrative, maintenance, and transportation expenses.	0.969	371/22
	Energy, water, and food are used efficiently, and waste and travel are well managed.	0.931	984/16
Environmental	Materials, medicines, and packaging are used without waste and properly consumed.	0.799	809/53
	Energy consumption management and efficiency improvements are carried out in the hospital.	0.863	965/21
	Air pollution and carbon emissions from travel, patient transport, and staff commuting have decreased.	0.840	312/100

	The hospital's plan complies with environmental and social standards.	0.712	623/8
	Waste from medicines, chemicals, other materials (e.g., equipment, products, packaging), and food is minimal.	0.944	281/13
	Toxic waste production has also decreased.	0.961	903/15
	The waste reuse/recycling/composting capacity in the hospital has increased.	0.833	355/24
Social	The mortality rate at the hospital has decreased.	0.832	441/39
	The rate of readmission has decreased.	0.805	008/56
	Healthcare is provided promptly.	0.766	969/14
	The reputation/brand image of the hospital among patients is good.	0.795	826/52
	Corruption and bribery do not exist in this hospital.	0.918	665/17
	The well-being of the population and stakeholder satisfaction have increased.	0.922	013/40

The bold values in Table 3 indicate that these values are greater than all the correlations between a single construct and the other constructs, demonstrating that the constructs are distinct. Therefore, discriminant validity is well established.

Table 3. Fornell-Larcker Criterion

Constructs	1	2	3	4
Big Data Analytical Capabilities	**0.910**			
Supply Chain Integration	0.833	**0.841**		
Lean Management	0.919	0.936	**0.803**	
Sustainable Supply Chain Performance	0.850	0.812	0.798	**0.894**

Common Method Bias (CMB)

Since the data were collected through a single-respondent survey, there is a potential risk of bias in the results. One such bias arises from respondents' tendency to provide answers they believe will be viewed positively by others, rather than responses that reflect their thoughts or feelings. This can lead to some survey questions being answered in a similarly skewed manner (Podsakoff & Organ, 1986). The questionnaire was designed to eliminate issues commonly found in the design phase that may reduce the respondents' ability to answer questions accurately. To address this, qualitative interviews were conducted with 30 experts to review the pilot questionnaires. Based on their feedback, several questions were revised to avoid design-related problems. Additionally, statistical analyses were performed to test for CMB in the model. First, the conservative version of Harman's single-factor test was used to confirm that the results were not biased due to a single respondent (Hulland et al., 2018). The findings of this test showed that the single factor explained 41.08% of the total variance, indicating that CMB is not a serious concern. On the other hand, causal relationships must be evaluated before hypothesis testing, as they can result in misestimations and misinterpretations that may lead to invalid conclusions (Dubey et al., 2019). Following the recommendations of Kock (2015), the Nonlinear Bivariate Causal Direction Ratio

(NLBCDR) was assessed. NLBCDR provides sufficient evidence to determine whether the hypothesized causal directions in the proposed model (Figure 1) are significantly stronger than the reverse directions (Kock, 2015). In this case, the observed NLBCDR value was 0.83, considerably higher than the acceptable threshold of 0.70. This suggests that the reverse causal relationship is insignificant for at least 83% of the model's paths. Therefore, it can be concluded that the issue of causality is not a serious concern in this study.

Structural Model Evaluation

The criteria recommended by Hair et al. (2019) were applied to evaluate the structural model. These include the coefficient of determination (R^2), predictive relevance (Q^2), and the statistical significance of the path coefficients. First, the R^2 values of the endogenous constructs were assessed. Hair et al. (2017) interpret R^2 values of 0.75, 0.50, and 0.25 as substantial, moderate, and weak, respectively. Based on these thresholds, the R^2 value for BDA Capability (0.714) was considered moderate. The R^2 values for Supply Chain Integration (0.763), Lean Management (0.789), and Sustainable Supply Chain Performance (0.848) were considered substantial. Next, Q^2 values were examined to assess the predictive accuracy of the structural model. According to the guidelines provided by Hair et al. (2011), Q^2 values significantly greater than zero indicate acceptable predictive relevance for an endogenous construct. The Q^2 value for BDA Capability was 0.638, for Supply Chain Integration it was 0.547, and for Lean Management it was 0.674—all of which reflect high predictive accuracy. The Q^2 value for Sustainable Supply Chain Performance was 0.496, indicating moderate predictive accuracy (Hair et al., 2019). Overall, the exogenous constructs demonstrated sufficient and significant predictive relevance for all endogenous constructs in the model.

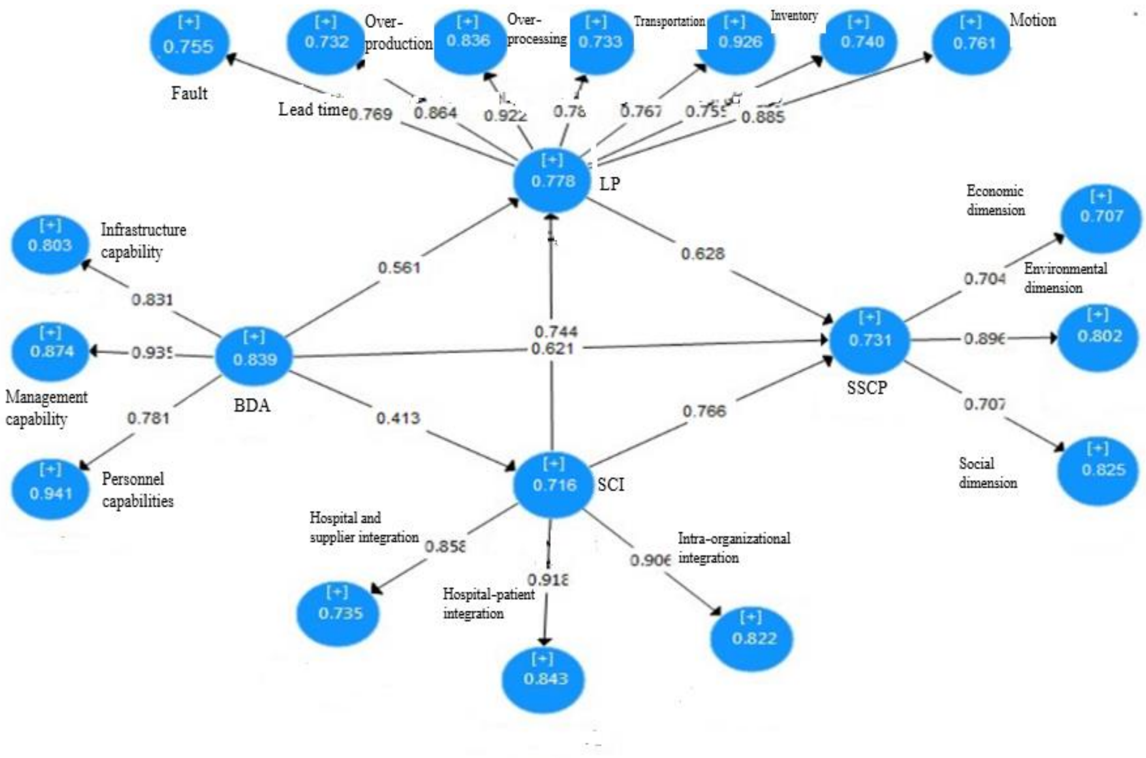

Figure 2. Results of the Structural Model Evaluation

Regarding the results of hypothesis testing, the statistical significance and strength of the path coefficients in the structural model were evaluated, as illustrated in Figure 2. BDA Capability positively affected Sustainable Supply Chain Performance ($\beta = 0.621$, $p < 0.001$), confirming Hypothesis H1. Additionally, BDA Capability had significant positive effects on Lean Management ($\beta = 0.561$, $p < 0.001$) and Supply Chain Integration ($\beta = 0.413$, $p < 0.001$), supporting Hypotheses H2 and H3, respectively. Hypothesis H4 was supported by the significant positive path from Supply Chain Integration to Lean Management ($\beta = 0.744$, $p < 0.001$), and Hypothesis H5 was confirmed by the significant positive path from Lean Management to Sustainable Supply Chain Performance ($\beta = 0.628$, $p < 0.001$). The path from Supply Chain Integration to Sustainable Supply Chain Performance also showed a significant positive effect ($\beta = 0.766$, $p < 0.001$), confirming Hypothesis H6. Furthermore, based on the structural model, the indirect effect of BDA Capability on Sustainable Performance through Lean Management was significant ($\beta = 0.352$, $p < 0.001$). Therefore, the null hypothesis is rejected, and the research hypothesis stating that BDA Capability significantly affects Sustainable Supply Chain Performance via Lean Management is accepted. Similarly, the indirect effect of BDA Capability on Sustainable Performance through Supply Chain Integration was also significant ($\beta = 0.316$, $p < 0.001$). Table 4 summarizes the results of the hypothesis testing.

Table 4. Test results of hypotheses

Hypotheses	Path Coefficient (β)	t-Statistic	P-Value	Result
H1: Big Data Analytics → Sustainable Supply Chain Performance	0.621	14.139	0.001	Confirmed
H2: Big Data Analytics → Lean Production	0.561	5.978	0.001	Confirmed
H3: Big Data Analytics → Supply Chain Integration	0.413	4.399	0.001	Confirmed
H4: Supply Chain Integration → Lean Production	0.744	9.405	0.001	Confirmed
H5: Lean Production → Sustainable Supply Chain Performance	0.628	11.215	0.001	Confirmed
H6: Supply Chain Integration → Sustainable Supply Chain Performance	0.766	8.964	0.001	Confirmed

Three independent formulas were used to examine the two remaining hypotheses of the study—concerning the mediating role of Lean Management and Supply Chain Integration in the relationship between BDA and Sustainable Supply Chain Performance (SSCP). The first method was the Sobel test, the most common approach for analyzing indirect effects and evaluating mediation. The second was the Aroian formula, and the third was the Goodman formula, each recognized by its name. Additionally, the Preacher & Hayes approach is referenced, typically using bootstrapping techniques for mediation analysis. If the Z-value in these tests exceeds 1.96, and the significance level (p-value) is less than 0.05, the mediating effect is considered statistically significant. The mediation analysis results for the variables Lean Management and Supply Chain Integration are presented in Table 5, indicating that the mediating effects of both variables are statistically significant across all three formulas.

Table 5. Results of Mediation Effect Analysis

Mediation variable	Formula	Significance level	P-Value	Type of relationship
H7: Big Data Analytics → Lean Production → Sustainable Supply Chain Performance	Sobel	2.65	0.01	Full Mediation
	Aroian	2.74	0.01	Full Mediation
	Goodman	2.71	0.01	Full Mediation
H8: Big Data Analytics → Supply Chain Integration → Sustainable Supply Chain Performance	Sobel	4.51	0.001	Full Mediation
	Aroian	4.33	0.001	Full Mediation
	Goodman	4.11	0.001	Full Mediation

Finally, an overall evaluation of the fitted model was conducted using structural equation modeling. For this purpose, the Goodness of Fit (GOF) index was used to assess the model's overall performance. This index ranges between 0 and 1, where values of 0.01, 0.25, and 0.36 indicate weak, moderate, and strong model fit, respectively. The GOF value calculated for this research model was 0.58, indicating a good model fit.

Discussion and Conclusion

The structural equation modeling test results indicated that BDA capabilities significantly and positively impact sustainable supply chain performance. This finding is consistent with prior research (Bag et al., 2020; Benzidia et al., 2021; Benzidia et al., 2024). The alignment with previous studies suggests that BDA capabilities play a crucial role in enhancing sustainable supply chain performance due to their ability to improve forecasting processes, identify improvement opportunities, and mitigate risks. This consistency may be attributed to the direct impact of data analytics technologies on responsiveness and flexibility in volatile environments, boosting the effectiveness of sustainability strategies. These analytical insights confirm the theoretical importance of data analytics technologies in achieving strategic goals in sustainable supply chains. Furthermore, the results demonstrated that BDA capabilities significantly positively impact the healthcare sector's lean operations and supply chain integration. This aligns with findings from other studies (Shokouhyar et al., 2020; Yu et al., 2021; Assaad & Sadiq-Kanaan, 2025). These results indicate that BDA capabilities are compatible with lean operations and supply chain integration strategies. Specifically, BDA supports lean supply chains by enhancing the detection of disruptions and sources of waste in operations. It also improves the efficiency of information and physical flows, strengthening the practical implementation of lean strategies. In addition, BDA can assist the healthcare sector by enabling the reconfiguration of internal and external resources through enhanced information sharing and collaboration within the supply chain.

The findings also showed that hospital supply chain integration positively affects lean operations. This is consistent with the research by Novais et al. (2020). This result is justified by the important role of supply chain integration in improving coordination, reducing inconsistencies, and increasing operational efficiency in healthcare. Process and information integration within the supply chain improves responsiveness and reduces costs, reinforcing the foundations of lean operations. Moreover, findings from other studies (Flynn et al., 2010; Izadyar et al., 2020; Mesquita et al., 2025) also highlight the critical impact of supply chain integration and lean operations on sustainability performance, which is aligned with this study’s findings. These results are justified by the key role of lean operations in improving processes, minimizing waste, and enhancing effectiveness in healthcare. By focusing on simplification and efficiency, lean strategies help reduce resource consumption, improve service quality, and maintain stability and sustainability in health systems. Also, integrating supply chain processes in healthcare increases responsiveness to patient needs and reduces unnecessary costs, directly impacting sustainability performance.

The findings indicate that the effect of BDA capabilities on sustainability performance can also be indirect, mediated by supply chain integration and lean operations. It can be concluded that BDA capabilities indirectly influence sustainability performance improvements. Supply chains must implement BDA technologies alongside lean approaches to achieve optimal sustainability performance. This finding aligns with prior studies suggesting that lean operations are a foundation and driver of sustainability performance (Zhou et al., 2018; Belhadi et al., 2020; Fayyaz et al., 2024; Mesquita et al., 2025). Regarding the influence of BDA on sustainable performance, some studies suggest that big data technologies can also impact sustainability indirectly by developing supply chain integration capabilities, collaboration, and flexibility (Benzidia et al., 2021). Therefore, proper integration of supply chain flows and a willingness to collaborate and share information are essential for improving supply chain sustainability.

Practical Implications

The findings of this study can serve as practical guidance for supply chain managers in the healthcare sector, particularly in leveraging BDA capabilities to support lean operations strategies and enhance supply chain integration, ultimately leading to improved sustainable performance. Since the application of big data technologies in healthcare is still in its early stages, this research can provide a foundation for purposefully integrating big data resources with supply chain strategies. The results suggest that using big data technologies directly contributes to sustainability improvements and facilitates the successful implementation of lean operations. This underscores the importance of considering the interconnection between BDA capabilities and lean principles when designing healthcare supply chain processes.

For example, demand forecasting based on big data analysis is most effective when applied in value-driven, waste-reduction processes. Case examples explored in this study also show that smart utilization of BDA can strengthen lean supply chain strategies. Accurate and up-to-date data optimizes production, distribution, and storage processes, reducing resource consumption and environmental impact. As a practical illustration, data analytics in a hospital can optimize the distribution and storage of medications and medical equipment, minimizing waste and ensuring more accurate and efficient patient response. Furthermore, data analytics can help maintain optimal inventory levels while increasing supply chain flexibility. With better forecasting of future needs, the system can avoid unnecessary stockpiling and allocate resources promptly. Risk analysis is another key benefit of big data technologies—early identification of potential threats allows for timely and effective corrective actions.

The study's results also show that enhancing supply chain integration as a first step yields tangible benefits for implementing lean strategies and improving sustainable performance. Since lean operations and integration share aligned supply chain goals, adopting a combined approach can enhance overall system productivity. However, there are some operational contradictions between the two. For example:

1. Lean operations emphasize inventory reduction,
2. While integration may require shared inventories for rapid responsiveness. Also, controlling and saving material flows is essential in lean conditions, whereas high integration requires ongoing communication with partners, potentially reducing direct control.

Here, BDA can serve as a key mediator. By improving forecast accuracy, increasing visibility, and facilitating collaboration among partners, these technologies help balance the requirements of both lean and integrated approaches. Through real-time and historical data analysis, organizations can reduce unnecessary inventories while maintaining responsiveness and flexibility. Moreover, advanced analytics enable the identification of improvement opportunities and foster trust among supply chain members.

Ultimately, this study introduces a virtuous cycle in which BDA capabilities enhance supply chain integration, strengthening lean operations. This process improves sustainability performance, which further justifies and encourages investment in data analytics technologies. As a result, organizations that successfully embed this cycle into their decision-making and implementation frameworks will gain a more sustainable competitive advantage in the healthcare industry.

Theoretical Implications

Given the limitations of the current study, it is recommended that future research focus on developing and applying BDA technologies in the healthcare sector, particularly during the early stages of implementation. This would comprehensively evaluate these technologies' direct and indirect impacts on sustainable performance and lean operations. Further studies are also necessary to assess how effectively data analytics can reduce internal and external conflicts between integration and lean strategies within the supply chain. In this regard, investigations exploring the tensions between lean operations' requirements (such as inventory reduction to eliminate waste) and the demands of supply chain integration (such as the need to maintain shared inventory or collaborative warehouses to increase flexibility and responsiveness) can offer valuable insights. As noted by some sources, conceptual conflicts between these two approaches are among the key barriers to implementing data-driven supply chains. BDA can help mitigate such conflicts by enhancing predictive capability and visibility. Therefore, studies that examine its mediating and moderating roles in this context will be particularly valuable. In addition, comparative studies among organizations with different levels of BDA implementation can help identify the key success factors and challenges in the digital transformation of the healthcare supply chain. Moreover, future-oriented research on optimizing investment in data analytics technologies and managing the associated risks could guide the development of more effective and sustainable strategies. Exploring cultural and structural differences among organizations and how these factors influence the efficiency and effectiveness of analytical technology implementation is also an important area for future research.

Continuing along this path, it is suggested that future studies be designed to develop integrated decision-making models based on BDA within the healthcare supply chain. These models should enable more effective decision-making in complex, data-driven environments while balancing sometimes conflicting objectives—such as lean operations, supply chain integration, and sustainability. Designing analytical frameworks or artificial intelligence algorithms that optimize resources, response time, and collaboration among supply chain members could help bridge the gap between theoretical research and practical applications in this field. Furthermore, it is recommended that future research examine the role of organizational contextual factors—such as hospital ownership type (public, private, or charitable), organizational structure (centralized or decentralized), and management styles—on the effectiveness of BDA implementation in the healthcare supply chain. Although some of this information was present in the data collected for the current study, it was not included in the analyses. Ignoring intervening variables could lead to oversimplified interpretations of the relationships between the study variables.

Therefore, examining these factors as moderators or mediators could lead to a deeper understanding of the differences in outcomes from implementing big data technologies in different organizations and help provide more precise and context-appropriate solutions. It is also advised that future studies consider such organizational characteristics not only as statistical control variables but as integral components of the theoretical design, thus contributing to the development of richer, more localized explanatory models in the context of the healthcare supply chain.

Data Availability Statement

Data available on request from the authors.

Acknowledgements

The authors would like to thank all the participants in the present study.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

Alshahrani, S., Rahman, S., & Chan, C. (2018). Hospital-supplier integration and hospital performance: evidence from Saudi Arabia. *The international journal of logistics management*, *29*(1), 22–45. https://doi.org/10.1108/IJLM-12-2016-0287

Benzidia, S., Bentahar, O., Husson, J., & Makaoui, N. (2024). Big data analytics capability in healthcare operations and supply chain management: The role of green process innovation. *Annals of Operations Research*, *333*(2), 1077-1101. https://doi.org/10.1007/s10479-022-05157-6

Bag, S., Yadav, G., Wood, L. C., Dhamija, P., & Joshi, S. (2020). Industry 4.0 and the circular economy: Resource melioration in logistics. *Resources Policy*, *68*, 101776. https://doi.org/10.1016/j.resourpol.2020.101776

Bagozzi, R. P., Yi, Y., & Nassen, K. D. (1998). Representation of measurement error in marketing variables: Review of approaches and extension to three-facet designs. *Journal of Econometrics*, *89*(1-2), 393–421. https://doi.org/10.1016/S0304-4076(98)00068-2

Bergenwall, A. L., Chen, C., & White, R. E. (2012). TPS's process design in American automotive plants and its effects on the triple bottom line and sustainability. *International Journal of Production Economics*, *140*(1), 374–384. https://doi.org/10.1016/j.ijpe.2012.04.016

Belhadi, A., Kamble, S. S., Zkik, K., Cherrafi, A., & Touriki, F. E. (2020). The integrated effect of Big Data Analytics, Lean Six Sigma, and Green Manufacturing on the environmental performance of manufacturing companies: The case of North Africa. *Journal of Cleaner Production*, *252*, 119903. https://doi.org/10.1016/j.jclepro.2019.119903

Benzidia, S., Makaoui, N., & Bentahar, O. (2021). The impact of big data analytics and artificial intelligence on green supply chain process integration and hospital environmental performance. *Technological forecasting and social change*, *165*, 120557. https://doi.org/10.1016/j.techfore.2020.120557

Bicheno, J., & Holweg, M. (2008). *The Lean toolbox: The essential guide to Lean transformation*. Picsie Books. https://orca.cardiff.ac.uk/id/eprint/25628

Castaldi, M., Sugano, D., Kreps, K., Cassidy, A., & Kaban, J. (2016). Lean philosophy and the public hospital. *Perioperative care and operating room management*, *3*, 25–28. https://doi.org/10.1016/j.pcorm.2016.05.006

Castillo, V. E., Mollenkopf, D. A., Bell, J. E., & Bozdogan, H. (2018). Supply chain integrity: A key to sustainable supply chain management. *Journal of Business Logistics*, *39*(1), 38–56. https://doi.org/10.1111/jbl.12176

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward a new theory. *International journal of physical distribution & logistics management*, *38*(5), 360–387. https://doi.org/10.1108/09600030810882816

Chen, D. Q., Preston, D. S., & Xia, W. (2013). Enhancing hospital supply chain performance: A relational view and empirical test. *Journal of Operations Management*, *31*(6), 391–408. https://doi.org/10.1016/j.jom.2013.07.012

Chen, I. J., & Paulraj, A. (2004). Towards a theory of supply chain management: the constructs and measurements. *Journal of Operations Management*, *22*(2), 119–150. https://doi.org/10.1016/j.jom.2003.12.007

De Vries, J., & Huijsman, R. (2011). Supply chain management in health services: an overview. *Supply chain management: An international journal*, *16*(3), 159-165. https://doi.org/10.1108/13598541111127146

De Souza, L. B. (2009). Trends and approaches in lean healthcare. *Leadership in health services*, *22*(2), 121–139. https://doi.org/10.1108/17511870910953788

Demirdöğen, G., Işık, Z., & Arayici, Y. (2020). Lean management framework for healthcare facilities integrating BIM, BEPS, and big data analytics. *Sustainability*, *12*(17), 7061. https://doi.org/10.3390/su12177061

Dobrzykowski, D. D., & Tarafdar, M. (2015). Understanding information exchange in healthcare operations: Evidence from hospitals and patients. *Journal of Operations Management*, *36*, 201-214. https://doi.org/10.1016/j.jom.2014.12.003

Drupsteen, J., van der Vaart, T., & Pieter van Donk, D. (2013). Integrative practices in hospitals and their impact on patient flow. *International Journal of Operations & Production Management*, *33*(7), 912-933. https://doi.org/10.1108/IJOPM-12-2011-0487

Davidson, R. K., Antunes, W., Madslien, E. H., Belenguer, J., Gerevini, M., Torroba Pérez, T., & Prugger, R. (2017). From food defence to food supply chain integrity. *British Food Journal*, *119*(1), 52–66. https://doi.org/10.1108/BFJ-04-2016-0138

Drupsteen, J., van der Vaart, T., & Van Donk, D. P. (2016). Operational antecedents of integrated patient planning in hospitals. *International Journal of Operations & Production Management*, *36*(8), 879-900. https://doi.org/10.1108/IJOPM-05-2014-0237

Dubey, R., Gunasekaran, A., Childe, S. J., Blome, C., & Papadopoulos, T. (2019). Big data and predictive analytics and manufacturing performance: integrating institutional theory, resource-based view, and big data culture. *British Journal of Management*, *30*(2), 341–361. https://doi.org/10.1111/1467-8551.12355

Duque-Uribe, V., Sarache, W., & Gutiérrez, E. V. (2019). Sustainable supply chain management practices and sustainable performance in hospitals: a systematic review and integrative. *Sustainability*, *11*(21), 5949. https://doi.org/10.3390/su11215949

Farhadi, F., Taghizadeh Yazdi, M. R., Momeni, M., & Sajadi, S. M. (2018). Providing Sustainable Supply Chain Agility Model in the Brick Industry of Isfahan Province. *Industrial Management Journal*, *10*(3), 335-352. (*in Persian*) https://doi.org/10.22059/imj.2018.261444.1007459

Flynn, B. B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of Operations Management*, *28*(1), 58–71. https://doi.org/10.1016/j.jom.2009.06.001

Fayyaz, A., Liu, C., Xu, Y., Khan, F., & Ahmed, S. (2024). Untangling the cumulative impact of big data analytics, green lean six sigma, and sustainable supply chain management on the economic performance of manufacturing organisations. *Production Planning & Control*, 1–18. https://doi.org/10.1080/09537287.2024.2348517

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*(1), 39–50. https://doi.org/10.1177/002224378101800104

Garrison, L. P. (2013). Universal health coverage—big thinking versus big data. *Value in Health*, *16*(1), S1-S3. http://dx.doi.org/10.1016/j.jval.2012.10.016

Gunasekaran, A., Papadopoulos, T., Dubey, R., Wamba, S. F., Childe, S. J., Hazen, B., & Akter, S. (2017). Big data and predictive analytics for supply chain and organizational performance. *Journal of Business Research*, *70*, 308–317. https://doi.org/10.1016/j.jbusres.2016.08.004

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed, a silver bullet. *Journal of Marketing Theory and Practice*, *19*(2), 139-152. https://doi.org/10.2753/MTP1069-6679190202

Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., & Thiele, K. O. (2017). Mirror, mirror on the wall: a comparative evaluation of composite-based structural equation modeling methods. *Journal of the academy of marketing science*, *45*, 616-632. https://doi.org/10.1007/s11747-017-0517-x

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European business review*, *31*(1), 2-24. https://doi.org/10.1108/EBR-11-2018-0203

Hulland, J., Baumgartner, H., & Smith, K. M. (2018). Marketing survey research best practices: evidence and recommendations from a review of JAMS articles. *Journal of the Academy of Marketing Science*, *46*, 92–108. https://doi.org/10.1007/s11747-017-0532-y

Izadyar, M., Toloie-Eshlaghy, A., & Seyed Hosseini, S. M. (2020). A model of sustainability performance assessment of LARG supply chain management practices in the automotive supply chain using system dynamics. *Industrial Management Journal*, *12*(1), 111–142. (*in Persian*) https://doi.org/10.22059/imj.2020.281292.1007594

Jeble, S., Dubey, R., Childe, S. J., Papadopoulos, T., Roubaud, D., & Prakash, A. (2018). Impact of big data and predictive analytics capability on supply chain sustainability. *The International Journal of Logistics Management*, *29*(2), 513–538. https://doi.org/10.1108/IJLM-05-2017-0134

Kock, N. (2019). From composites to factors: Bridging the gap between PLS and covariance-based structural equation modelling. *Information Systems Journal*, *29*(3), 674-706. https://doi.org/10.1111/isj.12228

Kline, R. B. (1998). Software review: Software programs for structural equation modeling: Amos, EQS, and LISREL. *Journal of psychoeducational assessment*, *16*(4), 343–364. https://doi.org/10.1177/073428299801600407

Kache, F., & Seuring, S. (2017). Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management. *International journal of operations & production management*, *37*(1), 10-36. https://doi.org/10.1108/IJOPM-02-2015-0078

Khan, S. A. R., Zkik, K., Belhadi, A., & Kamble, S. S. (2021). Evaluating barriers and solutions for social sustainability adoption in multi-tier supply chains. *International Journal of Production Research*, *59*(11), 3378–3397. https://doi.org/10.1080/00207543.2021.1876271

Kuo, M. H., Sahama, T., Kushniruk, A. W., Borycki, E. M., & Grunwell, D. K. (2014). Health big data analytics: current perspectives, challenges, and potential solutions. *International Journal of Big Data Intelligence*, *1*(1-2), 114-126. https://doi.org/10.1504/IJBDI.2014.063835

Moshtari, M. (2016). Inter-organizational fit, relationship management capability, and collaborative performance within a humanitarian setting. *Production and Operations Management*, *25*(9), 1542–1557. https://doi.org/10.1111/poms.12568

Mesquita, L. L., Lizarelli, F. L., & Duarte, S. (2025). Big data analytics and lean practices: impact on sustainability performance. *Production Planning & Control*, *36*(3), 333–356. https://doi.org/10.1080/09537287.2023.2267512

Moyano-Fuentes, J., & Sacristán-Díaz, M. (2012). Learning on lean: a review of thinking and research. *International Journal of Operations & Production Management*, *32*(5), 551–582. https://doi.org/10.1108/01443571211226498

Novais, L., Maqueira Marin, J. M., & Moyano-Fuentes, J. (2020). Lean production implementation, cloud-supported logistics, and supply chain integration: interrelationships and effects on business performance. *The International Journal of Logistics Management*, *31*(3), 629–663. https://doi.org/10.1108/IJLM-02-2019-0052

Nyaga, G. N., Young, G. J., & Zepeda, E. D. (2015). An analysis of the effects of intra-and interorganizational arrangements on hospital supply chain efficiency. *Journal of Business Logistics*, *36*(4), 340-354. https://doi.org/10.1111/jbl.12109

Novicka, J. (2025). Unpacking the Role of Big Data Analytics Capability in Sustainable Business Performance: Insights from Digital Sustainability Reporting Readiness in Latvia. *Sustainability*, *17*(8), 3666. https://doi.org/10.3390/su17083666

Narayanamurthy, G., & Gurumurthy, A. (2018). Is the hospital lean? A mathematical model for assessing the implementation of lean thinking in healthcare institutions. *Operations Research for Health Care*, *18*, 84–98. https://doi.org/10.1016/j.orhc.2017.05.002

Papadopoulos, T., Gunasekaran, A., Dubey, R., Altay, N., Childe, S. J., & Fosso-Wamba, S. (2017). The role of Big Data in explaining disaster resilience in supply chains for sustainability. *Journal of Cleaner Production*, *142*, 1108–1118. https://doi.org/10.1016/j.jclepro.2016.03.059

Putnik, G. D., & Putnik, Z. (2012). Lean vs Agile in the context of complexity management in organizations. *The Learning Organization*, *19*(3), 248-266. https://doi.org/10.1108/09696471211220046

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior research methods*, *40*(3), 879–891. https://doi.org/10.3758/BRM.40.3.879

Podsakoff, P. M., & Organ, D. W. (1986). Self-reports in organizational research: Problems and prospects. *Journal of Management*, *12*(4), 531–544. https://doi.org/10.1177/014920638601200408

Raghupathi, W., & Raghupathi, V. (2014). Big data analytics in healthcare: promise and potential. *Health information science and systems*, *2*, 1–10. https://doi.org/10.1186/2047-2501-2-3

Régis, T. K. O., Santos, L. C., & Gohr, C. F. (2019). A case-based methodology for lean implementation in hospital operations. *Journal of health organization and management*, *33*(6), 656–676. https://doi.org/10.1108/JHOM-09-2018-0267

Shokouhyar, S., Seddigh, M. R., & Panahifar, F. (2020). Impact of big data analytics capabilities on supply chain sustainability: A case study of Iran. *World Journal of Science, Technology and Sustainable Development*, *17*(1), 33–57. https://doi.org/10.1108/WJSTSD-06-2019-0031

Shahhoseini, M. A., Javaheri Shalmani, S. F., Hasangholipor Yasory, T., & Rostami, A. (2019). Evaluating and comparing key indicators of sustainable development performance in the petrochemical industry using SMAA and SMAA-S. *Industrial Management Journal*, *11*(2), 273–302. (*in Persian*) https://doi.org/10.22059/imj.2019.280703.1007589

Sajan, M.P., & Shalij, P.R. (2021). A multicase study approach in Indian manufacturing SMEs to investigate the effect of Lean manufacturing practices on sustainability performance. *International Journal of Lean Six Sigma*, *12*(3), 579-606. https://doi.org/10.1108/IJLSS-04-2020-0044

Srinivasan, R., & Swink, M. (2018). An investigation of visibility and flexibility as complements to supply chain analytics: An organizational information processing theory perspective. *Production and Operations Management*, *27*(10), 1849-1867. https://doi.org/10.1111/poms.12746

Suifan, T., Alazab, M., & Alhyari, S. (2019). Trade-off among lean, agile, resilient, and green paradigms: an empirical study on the pharmaceutical industry in Jordan using a TOPSIS-entropy method. *International Journal of Advanced Operations Management*, *11*(1-2), 69–101. https://doi.org/10.1504/IJAOM.2019.098493

Tambuskar, D. P., Jain, P., & Narwane, V. S. (2024). An exploration into the factors influencing the implementation of big data analytics in sustainable supply chain management. *Kybernetes*, *53*(5), 1710-1739. https://doi.org/10.1108/K-07-2022-1057

Tetteh, F. K., Nyamekye, B., Attah, J., Williams, E., Awumah, E. K., & Degbe, F. D. (2025a). Understanding when and how supply chain analytics, strategies, and desorptive capacity enhance healthcare supply chain performance. *The International Journal of Logistics Management*. https://doi.org/10.1108/IJLM-08-2024-0501

Wadmann, S., & Hoeyer, K. (2018). Dangers of the digital fit: Rethinking seamlessness and social sustainability in data-intensive healthcare. *Big Data & Society*, *5*(1), 2053951717752964. https://doi.org/10.1177/2053951717752964

Wang, Y., Kung, L., & Byrd, T. A. (2018). Big data analytics: Understanding its capabilities and potential benefits for healthcare organizations. *Technological forecasting and social change*, *126*, 3-13. https://doi.org/10.1016/j.techfore.2015.12.019

Wong, C. Y., Boon-Itt, S., & Wong, C. W. (2011). The contingency effects of environmental uncertainty on the relationship between supply chain integration and operational performance. *Journal of Operations Management*, *29*(6), 604-615. https://doi.org/10.1016/j.jom.2011.01.003

Yang, M. G. M., Hong, P., & Modi, S. B. (2011). Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. *International Journal of Production Economics*, *129*(2), 251-261. https://doi.org/10.1016/j.ijpe.2010.10.017

Yu, W., Zhao, G., Liu, Q., & Song, Y. (2021). Role of big data analytics capability in developing integrated hospital supply chains and operational flexibility: An organizational information processing theory perspective. *Technological Forecasting and Social Change*, *163,* 120417. https://doi.org/10.1016/j.techfore.2020.120417

Zhao, R., Liu, Y., Zhang, N., & Huang, T. (2017). An optimization model for green supply chain management by using a big data analytics approach. *Journal of Cleaner Production*, *142*, 1085–1097. https://doi.org/10.1016/j.jclepro.2016.03.006

Kuo, M. H., Chrimes, D., Moa, B., & Hu, W. (2015, December). Design and construction of a big data analytics framework for health applications. In *2015, IEEE International Conference on Smart City/SocialCom/SustainCom (SmartCity)* (pp. 631–636). IEEE. https://doi.org/10.1109/SmartCity.2015.140

Zhu, Q., Johnson, S., & Sarkis, J. (2018, January). Lean six sigma and environmental sustainability: a hospital perspective. In *Supply Chain Forum: An International Journal* (Vol. 19, No. 1, pp. 25–41). Taylor & Francis. https://doi.org/10.1080/16258312.2018.1426339

Singh, T., Poulose, J., & Sharma, V. (2025, March). Data-Driven Sustainability: Revolutionizing Hospital Supply Chains through Big Data Analytics. In *Operations Research Forum* (Vol. 6, No. 1, pp. 1–32). Springer International Publishing. https://doi.org/10.1007/s43069-025-00425-0

Assaad, A. S., & Sadek Kanaan, S. (2025, June). Supply chain integration based on big data, Internet of Things, marketing intelligence, and knowledge sharing. Study the SNOWA company in Iran. In *Supply Chain Forum: An International Journal* (pp. 1–17). Taylor & Francis. https://doi.org/10.1080/16258312.2025.2513214