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Innovative Strategies in Lean Supply Chain Management: Enhancing Efficiency in Healthcare

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Abstract

In the ever-evolving healthcare landscape, integrating Lean principles into supply chain management has emerged as a crucial strategy for enhancing efficiency and resource allocation. This paper explores recent advances in Lean Supply Chain Management (LSCM) within the healthcare sector and presents innovative strategies to optimize resource allocation. Synthesizing existing literature and case studies elucidates the principles of Lean thinking and their application to healthcare supply chains. Key topics addressed include waste reduction, process optimization, inventory management, and collaboration among stakeholders. Additionally, the role of technology and data analytics in streamlining supply chain operations is investigated. Furthermore, the paper delves into challenges and potential barriers to implementing LSCM in healthcare settings, along with recommendations for overcoming them. A comprehensive analysis of current trends and practices provides valuable insights for healthcare organizations seeking to enhance efficiency and effectiveness in their supply chain management practices.

Keywords: Lean Thinking; Healthcare Supply Chain; Efficiency; Resource Optimization; Technology Integration

1 Introduction

Lean Supply Chain Management (LSCM) is a business approach that integrates lean methods and principles throughout the supply chain to achieve world-class business performance [1]. It entails implementing lean concepts such as waste reduction and continuous improvement to maximize effectiveness and flexibility across the entire supply chain [2]. LSCM strives for continual improvement and waste elimination to enhance client value, speed, and quality. It is necessary to integrate lean principles throughout the supply chain to achieve significant improvements in performance [3]. Operational aspects, planning, and strategy implementation are prioritized in LSCM [2]. Unlike traditional supply chain management, which emphasizes control and pressure on partners, LSCM focuses on improving revenue and collaboration among partners [4]. The goals of LSCM are to examine supply chain operations across numerous organizations, simplify planning processes, and improve agile synchronization and variability management in global supply chains [5]. Implementing LSCM can lead to reduced expenses, greater operational performance, and increased corporate competitiveness, especially in the context of technological uncertainty [6]. Benefits such as better quality, faster delivery, and increased supply chain profitability could result from this, coupled with decreased costs and waste [7]. However, some LSCM efforts may face more challenges than others depending on the anticipated performance increase, and implementation tactics that are ill-considered can compromise the success of these programs [8]. Moreover, there may be difficulties in implementation, as each bundle of LSCM methods may not always produce the desired result.

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Lean management in the healthcare sector aims to reduce costs without sacrificing care quality [9]. Lean methodologies have been shown to significantly improve quality, efficiency, and safety in healthcare settings while using fewer resources [10]. Lean management can elevate the standard of patient care by enhancing clinical outcomes in a significant and lasting manner. The goal of lean healthcare is to maintain a hospital's financial stability while delivering excellent treatment to patients in an efficient, effective, and responsive manner [11]. Lean initiatives have resulted in benefits such as shorter wait times, cost savings, fewer errors, and higher levels of staff and patient satisfaction [12]. Better work environments, increased asset utilization, and higher patient satisfaction are potential outcomes of lean management in the healthcare industry [13]. Despite its growing popularity, there are still opportunities and challenges for organizations seeking to apply lean management principles in this sector [14]. Healthcare supply chains face specific challenges. Unlike manufactured goods, healthcare products must meet certain standards; thus, safe transportation is crucial. Precise planning, accurate demand forecasting, and efficient product distribution are essential for maintaining a successful healthcare supply chain [15]. While much research has been conducted on challenges such as inventory management and technology utilization, two areas that still need attention are personnel training and drug tracking [16]. Moreover, the COVID-19 pandemic exposed gaps in the healthcare supply chain, leading to delays and shortages [17]. To overcome these challenges, improved supply chain management is essential, which involves diversifying suppliers and implementing safety measures [18]. In the future, the adoption of global best practices and the formation of stronger alliances will shape the healthcare industry [19].

There have been significant turning points in the development of lean principles within the healthcare industry, showing how these ideas have been adapted and applied in this context. Similar demands in the healthcare sector during the 1990s led to the adoption of lean concepts [20]. Lean ideas such as "pull," controlling process flow, mapping value streams, defining value from the customer's perspective, and striving for perfection were eventually introduced and implemented in healthcare settings [21]. Since then, improvements in patient wait times, emergency department throughput, and bedside rounding procedures have been observed, ultimately contributing to an enhanced standard of medical care [22]. Technological developments are transforming supply chain management practices in the healthcare sector. The use of integrated information technology systems enables the adoption of lean and reverse logistics techniques, both of which are critical for improving healthcare delivery [23]. These solutions enhance quality, visibility, speed, and cost-effectiveness across the supply chain. Furthermore, smart technologies are being applied in novel supply chain applications to minimize waste and quickly respond to demand fluctuations [24]. Efficient healthcare supply chain management, which reduces waste and boosts operational performance, requires the integration of information technology and digitization [25]. Additionally, healthcare supply chains are gradually embracing circular economy principles to incorporate sustainable planning methods and reduce resource consumption [26]. Lean manufacturing concepts are gaining traction in the healthcare sector, albeit to varying degrees. These methods offer opportunities for cost reduction and higher-quality care [27].

2 Background of LSCM in Healthcare

Lean Supply Chain Management (LSCM) has evolved beyond being merely a set of methods and tools aimed at cost reduction [28]. The current focus is on adding value [29] by combining traditional lean techniques with various soft practices, including leadership, respect for people, kata, and dedicated management [30, 31]. Figure 1 illustrates the core principles of LSCM.

Figure 1: Core Principles of Lean Supply Chain Management

Lean SCM encompasses the following principles [28, 32, 33]:

- Identifying value from the customer's viewpoint.

- Finding and eliminating waste in the supply chain.
- Maintaining an uninterrupted value flow.
- Implementing a pull system to deliver supplies on schedule.
- Striving for excellence through continuous improvement.

The Toyota Production System, developed by the Japanese automaker Toyota, laid the foundation for Lean Healthcare Practice (LHP). Lean concepts, initially created for manufacturing processes, later found applications in other sectors, including industrial services and the public sector. As hospitals are integral to the healthcare system, many are adopting lean approaches to enhance efficiency and streamline operations [34]. The healthcare sector's shift towards process optimization and waste reduction reflects the adaptation of lean principles to its unique challenges. The fundamental lean principles of standardization, inventory reduction, and process improvement are aligned with the specific needs of healthcare organizations [35]. Lean's introduction into healthcare originated from its application in manufacturing to address inefficiencies such as long wait times in Canada's public healthcare system. In 2008, organizations like the Five Hills Health Region, St-Joseph's Health Center, and St-Boniface Hospital began experimenting with lean concepts, sparking formal discussions about the approach in Québec. In 2011, the Québec Ministry of Health and Social Services implemented lean principles across the province's healthcare network, with later phases extending the program to other organizations [36]. These efforts, through lean approaches, aimed to improve stakeholder satisfaction, quality of care, accessibility, and efficiency.

Table 1: Comparative Analysis of Lean Implementation: Healthcare vs. Manufacturing Sector

Aspect	**Healthcare Sector**	**Manufacturing Sector**
Nature of Operations	Close interaction with patients; customer-focused lean effectiveness; requires flexible, quick responses along multiple flow paths involving patients.	Focus on production processes; efficiency in production lines; emphasis on standardization and consistency.
Challenges and Pressures	Aging population, chronic diseases, rising costs; similar pressures as manufacturing faced in the 1990s.	Competitive market, cost reduction, improving production efficiency.
Application of Lean Tools	Involves mapping process flow, waste removal, and inventory optimization tailored to healthcare settings.	Utilizes traditional lean tools like 5S, Kanban, and continuous flow to optimize manufacturing processes.
Success Factors	Organizational leadership, employee knowledge about lean, training, patient satisfaction; crucial to educate and involve physicians in continuous improvement.	Strong management support, employee training, clear goals, and metrics for improvement.
Barriers	Resistance from healthcare practitioners, lack of lean knowledge among staff, complexity of healthcare processes.	Resistance to change, existing process inertia, initial cost of lean implementation.

The adoption of lean principles in the healthcare industry has produced significant results, particularly in terms of improving patient care and operational efficiency. Previous studies have reported positive outcomes, such as shorter hospital stays, reduced wait times, and enhanced accessibility to care. Furthermore, lean initiatives have been shown to boost operational performance, reduce costs, increase productivity, and optimize capacity in healthcare organizations [37]. Additionally, lean methods have fostered a positive work environment, motivated healthcare staff, and cultivated a culture of continuous improvement, leading to enhanced care and service quality for patients [38].

3 Recent Advances in Lean SCM in Healthcare

Recent developments in the healthcare industry's Lean Supply Chain Management (SCM) emphasize the importance of technological breakthroughs. Hospital supply chains can undergo a revolution due to the transformative techniques of big data analytics and artificial intelligence (AI). These systems help reduce waste and minimize supply shortages by prioritizing tasks such as inventory management, demand forecasting, and procurement [39]. Apart from technological advancements, Lean SCM has focused significantly on the integration of data analytics and predictive modeling. Predictive analytics is a crucial tool for improving decision-making and overall performance, and it is applied to optimize supply chain operations [40].

Moreover, the implementation of machine learning and sophisticated forecasting methodologies has played a pivotal role in mitigating inefficiencies in inventory management and demand forecasting in public healthcare systems. As a result, medication access and resource allocation have seen noticeable improvements [41]. Figure 2 illustrates the recent advances in Lean SCM in Healthcare.

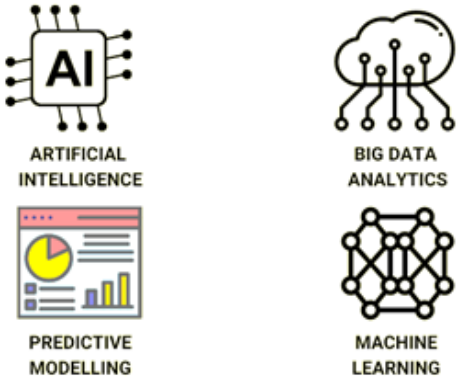

Figure 2: Recent Advances in Lean SCM in Healthcare

Research has shown significant positive correlations between supply chain innovation and lean healthcare practices. Lean approaches have been found to have a direct impact on enhancing supply chain innovation initiatives, highlighting the significance of lean approaches in fostering innovation in healthcare supply chains [42]. Furthermore, the major effect of predictive analytics on perceived profits and performance in supply chain management is emphasized [43], reinforcing the necessity of predictive analytics to streamline supply chain processes. AI improves the effectiveness of the supply chain by enabling data-driven decision-making. AI systems provide real-time insights that optimize inventory control, logistics, and procurement processes, resulting in lower costs and more efficient operations [44, 45]. AI algorithms process large volumes of data from diverse sources. Automated solutions, such as robotic process automation (RPA), reduce human error and enhance operational efficiency by handling repetitive tasks. Automation is another key component of AI technology. For instance, medical supply availability can be ensured on time with the help of automated order processing and inventory tracking, which drastically reduces processing times. One of the primary advantages of AI in healthcare supply chains is its enhancement of predictive analytics. To effectively estimate demand, AI and machine learning algorithms evaluate past data, seasonal trends, and external variables. This approach maintains optimal inventory levels and prevents stockouts or overstocks. Furthermore, AI systems provide insights into patient behavior and healthcare consumption patterns, aiding in forecasting future demand for specific drugs or medical supplies, ensuring that supply chains are prepared to meet patient needs [46].

AI-driven systems are crucial for resilience and disruption management during crises, such as pandemics, as they can quickly adjust to changing conditions by analyzing real-time data and developing contingency plans. Additionally, big data analytics help monitor and analyze various factors, such as vendor performance, geopolitical events, and logistical challenges, thereby improving supply chain resilience and responsiveness [47]. Machine learning algorithms can also identify potential disruptions in the supply chain and suggest alternative strategies to mitigate risks. AI further facilitates coordination and collaboration among stakeholders in the healthcare supply chain. AI-enabled game-theoretic models determine optimal pricing, profit-sharing, and innovation strategies, promoting collaboration and efficient resource allocation between manufacturers, suppliers, and healthcare providers. Integrated AI-powered platforms simplify supply chain management by ensuring seamless information exchange, coordination, transparency, and synchronization [48]. Finally, AI supports healthcare supply chains in their sustainability initiatives. AI leads to significant cost savings and economies of scale through waste reduction, productivity enhancement, and resource optimization. Additionally, AI-driven analytics can identify opportunities to reduce the environmental impact of supply chain operations, such as through sustainable sourcing practices and optimizing transportation routes to reduce carbon emissions [49].

4 Successful Implementation of Lean Supply Chain Management: Case Studies

Healthcare organizations around the world face constant challenges in maintaining cost-effectiveness while improving operational efficiency. This section highlights case studies where Lean Supply Chain Management (LSCM) has been successfully implemented.

4.1 Caldwell UNC Healthcare

This case study examines how Caldwell UNC Healthcare, a community hospital in North Carolina, successfully implemented Lean Supply Chain Management (LSCM), leading to significant cost reductions and operational improvements [50]. Facing the ongoing challenge of rising healthcare costs, Caldwell UNC Healthcare realized the necessity of streamlining its supply chain management processes. The hospital partnered with Simpler Consulting to integrate lean principles into their supply chain operations. The initial step involved a thorough evaluation of the hospital's supply chain, identifying substantial opportunities for improvement, particularly in employee productivity and inventory management. The success of this initiative was largely due to the active involvement of frontline workers, including doctors, nurses, and medical technicians. Information was gathered through observational research, internal documents, and consultations. Cost data and inventory levels were derived from internal records, while consultations with Simpler Consulting provided insights on improving efficiency and managing inventories more effectively.

Observational studies of frontline personnel helped to highlight workflow and inventory management procedures. The BlueBin system was used to track inventory levels in real-time. Performance metrics were developed based on baseline assessments, utilizing historical data on spending, production, and inventory levels. Lean management tools such as value stream mapping and root cause analysis were employed to streamline processes and eliminate non-value-added activities. Employee engagement was analyzed through task completion times and feedback, while cost savings were assessed by comparing pre- and post-implementation data. Ongoing oversight ensured long-term benefits and identified additional areas for savings. Triangulation ensured a comprehensive understanding of the process, with active participation from both frontline staff and management. Quantitative and qualitative analyses were conducted, examining employee feedback and cost reductions. Caldwell UNC implemented the following key strategies to achieve their objectives:

- **Inventory Management Optimization:** The hospital prioritized improving inventory utilization and eliminating excess inventory in all clinical departments. Through process redesign and collaboration with frontline workers, immediate efficiency gains were realized.
- **Visual Inventory Management Dashboard:** The implementation of the BlueBin system provided real-time visibility into inventory levels, empowering clinicians to make informed decisions. This data-driven approach enabled staff to optimize inventory management effectively.
- **Employee Productivity Enhancement:** By applying lean principles, the hospital optimized staff responsibilities and streamlined processes. Caldwell UNC was able to reduce labor-intensive tasks and increase productivity by redistributing work and leveraging the skills of its employees.

As a result of implementing LSCM, Caldwell UNC Healthcare achieved significant cost reductions. Over five months, the hospital realized savings of $2.62 million, with additional savings from reduced resource consumption and distribution costs. The development of employee empowerment and engagement greatly contributed to maintaining improvements across the organization. Despite the success of LSCM, Caldwell UNC Healthcare recognizes ongoing challenges, particularly in managing product pricing—especially in the pharmaceutical industry—and accommodating physician preferences amid technological advancements. The hospital remains committed to continuously improving its supply chain processes to further reduce healthcare costs and enhance patient care. The success of lean principles in healthcare supply chain management is evident from Caldwell UNC Healthcare's experience. The hospital achieved considerable cost savings and operational improvements through technology integration, active frontline worker participation, and a strategic focus on efficiency. This case study underscores the importance of proactive and strategic supply chain management to deliver high-quality, affordable healthcare services.

4.2 Sri Lankan Teaching Hospitals

The implementation of lean principles in Sri Lankan teaching hospitals aimed to increase efficiency, reduce waste, and raise the standard of patient care within the supply chain. The goal of this initiative was to enhance overall performance in the healthcare supply chain by identifying and eliminating activities that did not add value [51]. A methodical approach was adopted, combining both qualitative and quantitative techniques. Data were collected from 130 stakeholders, including physicians, nurses, medical laboratory technicians, radiographers, physiotherapists, pharmacists, medical students, and patients, through non-participant observations, interviews, and questionnaires. To evaluate current procedures and identify inefficiencies, lean tools such as Just-In-Time (JIT), Poka Yoke (error-proofing), continuous improvement (Kaizen), and value stream mapping were employed. Additionally, root cause analysis was conducted using RQDA analysis within the R studio environment. Lean implementation yielded notable improvements across several key areas. The Colombo South Teaching Hospital (CSTH) outperformed the Colombo North Teaching Hospital (CNTH) and the National Hospital of Sri Lanka (NHSL), with mean performance indicators ranging from 2.5 to 4.0. Major sources of waste identified included the unnecessary transfer of medications, frequent changes in the demand for medical supplies, and long lead times for various procedures. Operational improvements included enhanced workflow efficiency, reduced wait times, and fewer unnecessary supply movements. Costs were particularly reduced in the areas of prescription drugs and long-term care. This case study demonstrated the successful application of lean principles in the healthcare supply chains of Sri Lankan teaching hospitals. The implementation led to significant improvements in cost-effectiveness, service quality, and operational efficiency. The reduction in waste resulted in considerable cost savings, while better workflow and shorter patient wait times contributed to improved patient outcomes. The success of the CSTH initiative serves as a model for other hospitals, showcasing how Lean Six Sigma practices can be scaled and adapted to diverse healthcare settings.

5 Key Strategies for Lean Supply Chain Management in Healthcare

Key strategies for the success of Lean Supply Chain Management (LSCM) include streamlining inventory management to reduce waste, optimizing procurement processes to ensure timely and cost-effective sourcing of medical supplies, and fostering strong supplier relationships to enhance collaboration and reliability. Leveraging technology for real-time data analytics can enhance decision-making and responsiveness, while continuous process improvement initiatives, such as Kaizen, can help identify and eliminate inefficiencies. By adopting these strategies, healthcare organizations can create a more agile, cost-effective, and patient-centered supply chain. Figure 3 represents the key strategies necessary for the success of LSCM in healthcare.

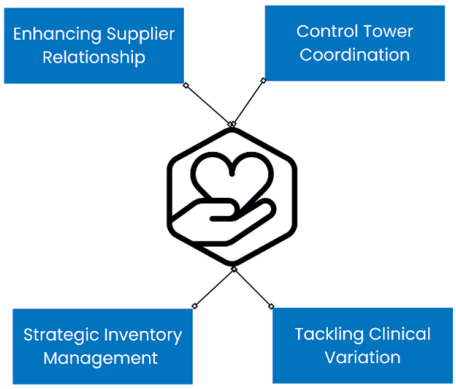

Figure 3: Key Strategies for Lean Supply Chain Management in Healthcare

5.1 Inventory Management Strategies

Effective inventory management is essential in the healthcare industry because it impacts both patient care and operating expenses [52]. Proper inventory management is vital to ensuring that patients receive timely, high-quality care while simultaneously reducing costs [53]. Challenges such as overstocking or shortages of supplies, particularly during crises like the COVID-19 pandemic, underscore the importance of efficient inventory management. Various approaches and methodologies, such as Economic Order Quantity (EOQ), Mathematical Optimization Models, and Metaheuristics, have been developed to model hospital inventory management effectively [54]. Furthermore, healthcare facilities are encouraged to integrate modern technologies such as artificial neural networks and radiofrequency identification (RFID) to optimize inventory control [52, 53]. Key inventory control methods in healthcare include ABC, VED, FSN, and SDE analyses [53]. However, several challenges exist in implementing inventory management systems in healthcare, including inaccurate data, poor staff training, and a lack of consistency. Despite these difficulties, a thorough understanding of the unique needs and challenges faced by healthcare facilities is crucial for successful implementation [52].

5.2 Just-in-Time (JIT) Inventory Systems Strategies

Implementing Just-in-Time (JIT) inventory methods is crucial for reducing waste and preventing overstocking in healthcare supply chains. By ordering and receiving supplies only when they are needed, healthcare facilities can significantly reduce costs and improve patient care. This can be achieved through close collaboration with suppliers and the use of technological solutions [51]. JIT inventory management has introduced a revolutionary approach to improving organizational efficiency and patient care in healthcare supply chain management. Research has demonstrated that JIT effectively reduces waste and enhances service quality, leading to observable savings in operating expenses [55]. Comparative studies highlight the superiority of organizations that adopt JIT, underscoring the critical role JIT plays in improving overall performance [56]. However, it is essential to acknowledge the risks associated with JIT, particularly concerning supply chain disruptions, which require careful planning and risk mitigation strategies [57]. By applying JIT principles, healthcare institutions can navigate the complexities of the healthcare landscape, streamline processes, allocate resources more efficiently, and ultimately improve patient outcomes.

5.3 Collaboration and Partnership Strategies

Collaboration and partnership strategies are essential to Lean Supply Chain Management (LSCM) in healthcare as they promote efficiency and integration [57]. These strategies enable seamless coordination between hospitals and suppliers through cooperative planning, execution, and decision-making processes. Decisions related to suppliers and partnerships are critical because collaborative partnerships offer benefits such as resource access and risk sharing [58]. Furthermore, a cost-benefit sharing framework highlights the importance of cooperation in reducing costs, managing risks, and enhancing performance [59]. Successful collaboration is ensured through the equitable distribution of costs and rewards among stakeholders, fostering mutual gains.

Increasing cooperation among stakeholders—including suppliers, physicians, and administrators—is crucial to optimizing inventory control and achieving efficiency in healthcare supply chain management. Collaborative initiatives, such as vendor-managed inventory (VMI) programs and strategic alliances, facilitate precise inventory monitoring, timely replenishment, and cost-effective resource allocation, ultimately leading to improved patient outcomes and operational performance [51].

5.4 Demand Forecasting and Capacity Planning Strategies

Accurate demand forecasting and capacity planning are vital for the efficient allocation of resources in healthcare settings. By utilizing data analytics tools to predict demand patterns, healthcare organizations can improve operational efficiency and cost-effectiveness by optimizing inventory levels and ensuring timely resource availability [51]. Table 2 illustrates how various strategies contribute to effective resource allocation in healthcare supply chain management.

Table 2: Strategies for Lean Supply Chain Optimization in Healthcare

Aspect	Description	Solution
Reducing Inventory and Shortage Costs	Demand forecasting errors lead to high inventory and shortage costs [60].	Utilize artificial neural networks for accurate demand forecasting to minimize costs [60].
Improving Medication Ordering	Accurate demand estimation and agile delivery are essential [61].	Implement the Kanban system for accurate demand estimation and waste reduction [61].
Optimizing Supply Chain Configuration	Optimization driven by accurate demand forecasting enhances efficiency [15].	Optimize supply chain configuration and distribution based on precise forecasting [15].

6 Challenges and Barriers for Implementation of Lean SCM in Healthcare

Healthcare organizations face several obstacles when implementing Lean Supply Chain Management (SCM), including technological, regulatory, cultural, and financial challenges.

6.1 Technological Obstacles

Technological challenges to the adoption of Lean SCM include inadequate internet access, inconsistent infrastructure, and environmental unpredictability. While digitization and information technology are recognized as essential tools for improving medical supply chains, achieving an efficient supply chain remains difficult without a robust technological foundation [62].

6.2 Regulatory Obstacles

Regulatory hurdles significantly impact the coordination of supply chains in healthcare. These regulatory concerns, along with the unique characteristics of the healthcare network, have a considerable influence on the effectiveness of healthcare SCM activities [63, 64].

6.3 Cultural Challenges

Cultural factors within healthcare organizations—such as corporate culture, leadership, and employee involvement—play a critical role in the success of lean healthcare initiatives [59]. Additionally, issues related to professionalism, implementation fidelity, and the demand for evidence-based research complicate the implementation and sustainability of Lean SCM in healthcare settings [65].

6.4 Financial Challenges

Financial constraints are a significant barrier to the implementation of Lean SCM, particularly in the areas of skill development, ongoing maintenance, and adaptation to regulatory changes [66]. However, lean SCM projects provide healthcare organizations with the opportunity to address budgetary challenges by improving drug distribution systems, ensuring patient safety, optimizing instrument utilization, and managing supply chain costs more effectively [67]. Figure 4 highlights the challenges in implementing Lean SCM in healthcare.

6.5 Addressing Technological Challenges

Overcoming technological challenges requires a multi-faceted approach. Tools such as Fuzzy-AHP can prioritize efforts based on potential performance gains, ensuring effective resource allocation [68]. For system-wide Lean adoption, it is necessary to integrate social, technical, and external components, which ensures system compatibility [69]. Additionally, careful planning, input from healthcare professionals, and the integration of Industry 4.0 technologies—such as IoT, big data, and AI—alongside Lean methodologies improve operational performance [70]. Successful large-scale Lean deployments require completing transitional phases over several years, along with dynamic cross-case analysis, demanding perseverance and patience [71].

6.6 Addressing Cultural Challenges

Cultural resistance to lean concepts in healthcare can be mitigated through effective communication, collaboration strategies, and an understanding of organizational transformation via models like the "contingent Lean culture adoption" model [72]. Healthcare providers must address specific behavioral drivers of resistance [73]. Since organizational culture heavily

Figure 4: Challenges in Implementing Lean SCM in Healthcare

influences lean implementation, targeted strategies to reduce defensive mechanisms are essential [74]. Integrated and coordinated efforts—such as robust change management and employee involvement—are key to successfully implementing lean principles [69].

6.7 Addressing Regulatory Challenges

Several best practices are crucial for overcoming regulatory barriers to Lean SCM implementation in healthcare. Customizing terminology and symbols to fit a patient-centered approach ensures effective communication and regulatory compliance. Clear communication and employee incentives help overcome resistance from practitioners and ensure adherence to regulatory standards [75]. Lean initiatives can remain compliant through strong leadership and comprehensive training programs [76]. Identifying facilitators such as organizational shortcomings and barriers like a lack of awareness and inadequate support aids in navigating regulatory complexities [77]. A practice-driven methodology, initiated by strategic planning and sustained through ongoing improvement efforts, systematically addresses regulatory obstacles [78].

6.8 Addressing Financial Challenges

Several practical strategies can be employed to overcome financial obstacles to Lean SCM implementation in healthcare. Adopting patient-centered terminology and symbols streamlines processes and reduces costs associated with misunderstandings and inefficiencies [74]. Clear communication and motivating healthcare practitioners help minimize resistance, maximize resource utilization, and reduce implementation costs [74]. Competent leadership and thorough training prepare the workforce for Lean interventions, reducing the risk of errors and costly rework [76]. Financial challenges can be systematically addressed by identifying organizational inadequacies and obstacles, such as a lack of support and knowledge gaps, while ensuring optimal resource allocation through strategic planning and continuous improvement programs [77, 78].

7 Future Directions and Opportunities for Lean SCM in Healthcare

The future trajectory of Lean Supply Chain Management (SCM) in healthcare is poised for significant advancements driven by technological innovation, strategic partnerships, and enhanced operational efficiencies. Building upon current trends, several key areas emerge as critical for shaping the future landscape of Lean SCM:

- **Global Standardization and Scalability:** Global standardization of Lean SCM frameworks will be essential for facilitating benchmarking and scalability across diverse healthcare systems [79]. By implementing standardized processes,

healthcare organizations can improve quality and efficiency consistently, while adapting more easily to various operational and regulatory environments. This standardization will also foster cross-border collaboration and the exchange of best practices, promoting continuous improvement on a global scale.

- **Expansion into Outpatient and Community Healthcare:** Expanding Lean SCM principles beyond traditional hospital settings to outpatient clinics and community healthcare centers presents a significant opportunity [80]. By implementing Lean approaches in decentralized care environments, healthcare organizations can optimize resource allocation, streamline supply chain operations, and increase patient access to essential medical supplies and services. Tailored Lean solutions will drive efficiency across the continuum of care, with a focus on patient-centricity, agility, and flexibility in outpatient care.

- **Integration of Advanced Technologies:** The integration of advanced technologies, such as artificial intelligence (AI), machine learning (ML), and the Internet of Things (IoT), will redefine Lean SCM practices in healthcare [81]. AI and ML algorithms can transform inventory control and demand forecasting accuracy, enabling proactive risk management and real-time decision-making. IoT-enabled devices will enhance supply chain visibility and traceability, ensuring timely replenishment and reducing waste. Additionally, big data-driven predictive analytics will optimize distribution and logistics networks, improving overall operational resilience and efficiency.

- **Collaboration Across the Healthcare Ecosystem:** Collaboration will be paramount in future Lean SCM initiatives, fostering seamless integration and coordination across the healthcare supply chain ecosystem [82]. Strategic alliances between hospitals, insurance providers, drug manufacturers, and equipment suppliers will streamline procurement processes, promote price transparency, and reduce supply chain risks. Joint efforts, such as vendor-managed inventory (VMI) programs and shared logistics platforms, will enhance supply chain responsiveness and resilience, ensuring uninterrupted services in times of disruption.

- **Enhanced Quality Metrics and Performance Measurement:** Future Lean SCM strategies will prioritize comprehensive quality metrics that extend beyond traditional measures to encompass patient outcomes, safety, operational efficiency, and cost-effectiveness [79]. Sophisticated performance measurement tools will enable healthcare organizations to assess the overall impact of Lean initiatives and identify areas for targeted improvement. Data-driven insights and continuous feedback loops will drive the pursuit of ongoing improvement, ultimately enhancing patient satisfaction and healthcare delivery.

- **Resilience and Adaptive Strategies:**

  Building resilience into Lean SCM practices will be critical for mitigating risks posed by global disruptions and healthcare crises [83]. Future initiatives will emphasize adaptive logistical frameworks, flexible sourcing strategies, and comprehensive contingency planning. By implementing multi-grade fuzzy logic and scenario planning methodologies, healthcare organizations will enhance supply chain agility and preparedness, allowing them to respond quickly to unforeseen challenges while maintaining lean principles of efficiency and waste reduction.

- **Innovation in Waste Reduction and Process Optimization:**

  Innovation will continue to drive waste reduction and process optimization in healthcare supply chains [79]. By combining Kaizen events with Lean Six Sigma methodologies, healthcare organizations can foster a culture of operational excellence and innovation. Embracing digital transformation efforts and emerging technologies will further maximize workflow efficiency, automate repetitive tasks, and eliminate non-value-added activities. This unwavering focus on innovation will enable healthcare organizations to deliver high-quality care affordably while adapting to changing patient needs and market dynamics.

- **Sustainability and Ethical Sourcing:** Long-term sustainability and ethical sourcing practices will increasingly shape Lean SCM strategies in healthcare [79]. Healthcare organizations will prioritize partnerships with suppliers committed to social responsibility and environmental stewardship. Sustainable procurement strategies, such as green logistics and circular economy principles, will reduce environmental impact and maximize resource efficiency.

By incorporating sustainability into Lean SCM frameworks, healthcare organizations can enhance their brand reputation, minimize regulatory risks, and contribute to global health and environmental goals. The future of Lean SCM in healthcare is bright, driven by strategic partnerships, technological innovation, and a commitment to sustainability. By embracing these future directions—global standardization, technology integration, expansion into decentralized care, ecosystem collaboration, enhanced metrics, resilience strategies, innovation, and sustainability—healthcare organizations can achieve significant improvements in efficiency, cost-effectiveness, and patient outcomes. Continued research and the application of these advanced Lean approaches will be essential for navigating complexity and capitalizing on opportunities in healthcare supply chain management.

8 Conclusion

The implementation of Lean Supply Chain Management (LSCM) in the healthcare industry is a transformative strategy that enhances operational efficiency, reduces costs, and improves the quality of patient care. By incorporating lean principles such as waste reduction and continuous improvement, healthcare organizations can optimize their supply chain operations. The case study of Caldwell UNC Healthcare demonstrates the significant achievements that can be realized through effective LSCM implementation, including notable cost savings and operational improvements. Technological advancements, such as artificial intelligence and big data analytics, further optimize demand forecasting, resource allocation, and inventory management. These technologies help healthcare providers reduce waste, mitigate supply shortages, and enhance overall supply chain performance. In addition, collaborative partnerships and accurate demand forecasting are critical for ensuring efficient resource allocation and streamlined operations. Despite its immense potential, the implementation of LSCM in healthcare presents several challenges. Barriers to successful adoption include inadequate digital infrastructure, regulatory restrictions, cultural resistance, and financial limitations. Overcoming these obstacles requires a robust digital infrastructure, effective regulatory navigation, a culture of continuous improvement, and sound financial management. Looking forward, LSCM holds great promise for transforming healthcare supply chains. Lean principles can be extended to outpatient services, and comprehensive quality metrics can be developed to further improve patient care and overall healthcare efficiency. Strategic partnerships with stakeholders—including insurance providers, pharmaceutical companies, and equipment suppliers—can enhance resource utilization and patient care delivery. The future of healthcare LSCM depends on continuous innovation, flexibility, and collaboration. By seizing these opportunities, healthcare organizations can maximize efficiency throughout the supply chain, ensuring high-quality and cost-effective patient care. This approach will contribute to the sustainability and resilience of healthcare delivery globally, addressing current challenges while preparing healthcare systems to meet future demands.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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Author Contribution

Ginnel Quadras: Conceptualization and writing—original draft preparation and visualization; **Ali Talyshinskii**: Data curation and writing-original draft preparation; **Suhas Kowshik**: Visualization and Investigation.

References

[1] M. J. Schniederjans, D. G. Schniederjans, Q. Cao, and V. C. Gu, *Topics in Lean Supply Chain Management*. World Scientific, January 2018.

[2] J. Moyano-Fuentes, S. Bruque-Cámara, and J. M. Maqueira-Marín, "Development and validation of a lean supply chain management measurement instrument," *Production Planning & Control*, vol. 30, pp. 20–32, January 2019.

[3] M. Asmae, A. En-Nadi, and B. Herrou, "The integration of lean manufacturing in supply chain: Principles, wastes and tools," in *2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA)*, pp. 1–6, IEEE, December 2020.

[4] G. L. Tortorella, R. F. Miorando, C. E. Fries, and G. A. Marodin, "Lean supply chain: Empirical research on practices and performance," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 108–119, April 2017.

[5] J. Packowski and P. Streuber, "Integration of lean scm," *Pharmaceutische Industrie*, vol. 76, no. 7, pp. 1041–1045, 2014.

[6] Strategic Direction, "Lean supply chain management strategy: Addressing uncertainty and driving performance," *Strategic Direction*, vol. 26, no. 8, 2010.

[7] B. Cvetić, D. Vasiljevic, J. Novakovic, and A. Đorđevic, "Lean supply chain: Take an opportunity to do more with less," *Tehnicki Glasnik*, vol. 15, pp. 275–281, June 2021.

[8] G. L. Tortorella, R. Giglio, and J. Limon-Romero, "Supply chain performance: how lean practices efficiently drive improvements," *Journal of Manufacturing Technology Management*, vol. 29, pp. 829–845, April 2018.

[9] I. R. Lasorsa, G. Liuzzi, R. A. Calabrese, and A. Accardo, "An innovative method for standardizing lean management approach in hospitals," in *16th Nordic-Baltic Conference on Biomedical Engineering*, pp. 67–70, Springer International Publishing, 2015.

[10] L. D. Martin, S. E. Rampersad, D. K. Low, and M. A. Reed, "Process improvement in the operating room using toyota (lean) methods," *Colombian Journal of Anesthesiology*, vol. 42, pp. 220–228, July 2014.

[11] A. H. Iswanto, *Lean Implementation in Hospital Departments: How to Move from Good to Great Services*. Productivity Press, March 2019.

[12] L. Burroni, C. Bianciardi, C. Romagnolo, C. Cottignoli, A. Palucci, F. M. Fringuelli, G. Biscontini, and J. Guercini, "Lean approach to improving performance and efficiency in a nuclear medicine department," *Clinical and Translational Imaging*, vol. 9, pp. 129–139, April 2021.

[13] G. R. Baker, "Improving healthcare using lean processes," *Healthcare Quarterly*, vol. 17, no. 2, pp. 18–19, 2014.

[14] E. Vitaskova, "Is czech health care going to be lean?," *Scientific Papers of the University of Pardubice. Series D, Faculty of Economics and Administration*, vol. 34, 2015.

[15] S. Ashtab and W. Anderson, "Differences in manufacturing and healthcare supply chain management: an overview," *International Journal of Healthcare Technology and Management*, vol. 20, no. 3, pp. 232–248, 2023.

[16] D. Emmett, "Supply chains in healthcare organizations: lessons learned from recent shortages," *Hospital Topics*, vol. 97, pp. 133–138, October 2019.

[17] J. Gattorna, "The healthcare supply chain applying best-practice remedies to the healthcare sector," in *Strategic Supply Chain Alignment*, pp. 587–601, Routledge, March 2017.

[18] J. Gattorna, ed., *Strategic Supply Chain Alignment: Best Practice in Supply Chain Management*. Routledge, March 2017.

[19] H. Aronsson, M. Abrahamsson, and K. Spens, "Developing lean and agile health care supply chains," *Supply Chain Management: An International Journal*, vol. 16, pp. 176–183, May 2011.

[20] N. Wickramasinghe, L. Al-Hakim, C. Gonzalez, and J. Tan, eds., *Lean Thinking for Healthcare*. Springer New York, 2014.

[21] T.-G. Meng and P. Choo, "Cultivating an innovative culture through lean," in *Innovations in Healthcare Management: Cost-Effective and Sustainable Solutions* (V. K. Pervez and R. L. Shrivastava, eds.), pp. 69–81, CRC Press, February 2015.

[22] N. Houchens and C. S. Kim, "The application of lean in the healthcare sector: theory and practical examples," in *Lean Thinking for Healthcare* (N. Wickramasinghe, L. Al-Hakim, C. Gonzalez, and J. Tan, eds.), pp. 43–53, Springer New York, 2014.

[23] B. Y. Kasula, "Revolutionizing healthcare delivery: Innovations and challenges in supply chain management for improved patient care," *Transactions on Latest Trends in Health Sector*, vol. 15, December 2023.

[24] S. Nizetic, N. Djilali, A. Papadopoulos, and J. J. P. C. Rodrigues, "Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management," *Journal of Cleaner Production*, vol. 231, pp. 565–591, September 2019.

[25] M. Beaulieu and O. Bentahar, "Digitalization of the healthcare supply chain: A roadmap to generate benefits and effectively support healthcare delivery," *Technological Forecasting and Social Change*, vol. 167, p. 120717, June 2021.

[26] K. Govindan and M. Hasanagic, "A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective," *International Journal of Production Research*, vol. 56, pp. 278–311, January 2018.

[27] B. Poksinska, "The current state of lean implementation in health care: literature review," *Quality Management in Healthcare*, vol. 19, pp. 319–329, October 2010.

[28] J. P. Womack and D. T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon and Schuster, 1996.

[29] R. Jugulum and P. Samuel, *Design for Lean Six Sigma: A Holistic Approach to Design and Innovation*. John Wiley & Sons, January 2010.

[30] G. Adams, "The lean enterprise: Designing and managing strategic processes for customer-winning performance," *Quality Progress*, vol. 31, p. 150, August 1998.

[31] M. Rother, *Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results*. McGraw-Hill, 2009.

[32] J. P. Womack and D. T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon and Schuster, 1996.

[33] G. Plenert, *Reinventing Lean: Introducing Lean Management into the Supply Chain*. Elsevier, July 2010.

[34] M. Ortiz-Barrios, D. Coba-Blanco, G. Jiménez-Delgado, V. A. Salomon, and P. López-Meza, "Implementation of lean six sigma to lessen waiting times in public emergency care networks: A case study," in *International Conference on Human-Computer Interaction*, (Cham), pp. 83–93, Springer, 2021.

[35] T. Joosten, I. Bongers, and R. Janssen, "Application of lean thinking to health care: Issues and observations," *International Journal for Quality in Health Care*, vol. 21, pp. 341–347, October 2009.

[36] D. B. Henrique and M. Godinho Filho, "A systematic literature review of empirical research in lean and six sigma in healthcare," *Total Quality Management & Business Excellence*, vol. 31, pp. 429–449, February 2020.

[37] A. D'Andreamatteo, L. Ianni, F. Lega, and M. Sargiacomo, "Lean in healthcare: A comprehensive review," *Health Policy*, vol. 119, pp. 1197–1209, September 2015.

[38] E. Drotz and B. Poksinska, "Lean in healthcare from employees' perspectives," *Journal of Health Organization and Management*, vol. 28, pp. 177–195, May 2014.

[39] M. Allahham, A. A. Sharabati, H. Hatamlah, A. Y. Ahmad, S. Sabra, and M. K. Daoud, "Big data analytics and ai for green supply chain integration and sustainability in hospitals," in *Magboul, I., Jebreel, M., Dweiri, M., Qabajeh, M., Al-Shorafa, A., & Ahmad, A. 2024:921-34*, 2024.

[40] I. Pradhan, D. Sarwar, and A. Hosseinian-Far, "Impact of predictive analytics on the strategic business models of supply chain management," in *Integrated Business Models in the Digital Age: Principles and Practices of Technology Empowered Strategies*, pp. 207–249, Cham: Springer, June 2022.

[41] S. S. Bhat, V. R. Srihari, A. Prabhune, S. S. Satheesh, and A. B. Bidrohi, "Optimizing medication access in public healthcare centers: A machine learning stochastic model for inventory management and demand forecasting in primary health services," in *2024 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE)*, pp. 1–5, IEEE, January 2024.

[42] N. F. Habidin, N. A. Shazali, N. Ali, N. A. Khaidir, and N. H. Jamaludin, "Exploring lean healthcare practice and supply chain innovation for malaysian healthcare industry," *International Journal of Business Excellence*, vol. 7, no. 3, pp. 394–410, 2014.

[43] A. Nag, N. Choudhary, D. Sinha, A. P. Sinha, and S. Mishra, "Predictive analytics-new business intelligence in scm," *International Journal of Value Chain Management*, vol. 14, no. 3, pp. 325–345, 2023.

[44] M. M. Bhanushali, S. Bhardwaj, N. K. Singh, P. Vijayalakshmi, N. Mazumdar, and P. B. Acharjee, "From automation to optimization: Exploring the effects of ai on supply chain management," in *Utilization of AI Technology in Supply Chain Management*, pp. 77–94, IGI Global, 2024.

[45] T. J. Nagalakshmi, A. Shameem, A. Somaiah, S. Lakhanpal, M. Tiwari, and J. A. Dhanraj, "The financial dynamics of ai-enhanced supply chain management: Trends and insights," in *Utilization of AI Technology in Supply Chain Management*, pp. 208–224, IGI Global, 2024.

[46] I. A. Shah, N. Z. Jhanjhi, and S. K. Ray, "Artificial intelligence applications in the context of the security framework for the logistics industry," in *Advances in Explainable AI Applications for Smart Cities*, pp. 297–316, IGI Global, 2024.

[47] G. Arji, H. Ahmadi, P. Avazpoor, and M. Hemmat, "Identifying resilience strategies for disruption management in the healthcare supply chain during covid-19 by digital innovations: A systematic literature review," *Informatics in Medicine Unlocked*, vol. 38, p. 101199, January 2023.

[48] A. Adhikari, R. Joshi, and S. Basu, "Collaboration and coordination strategies for a multi-level ai-enabled healthcare supply chain under disaster," *International Journal of Production Research*, pp. 1–27, September 2023.

[49] M. I. Khan and M. F. Khan, "Applications of artificial intelligence in sustainable supply chain management in the medical sector," in *AI Applications for Business, Medical, and Agricultural Sustainability*, pp. 23–46, IGI Global, 2024.

[50] S. T. Khorasani, J. Cross, and O. Maghazei, "Lean supply chain management in healthcare: a systematic review and meta-study," 2020.

[51] A. R. Wijewardana and T. D. Rupasinghe, "Lean healthcare framework for sri lankan healthcare supply chains: A case study of teaching hospitals," *Universal Journal of Management*, vol. 4, no. 10, pp. 517–527, 2016.

[52] J. Refonaa, S. J. Shabu, K. D. Paul, S. Dhamodaran, and V. A. Mary, "Medistock: Medical inventory management system," in *2023 4th International Conference on Electronics and Sustainable Communication Systems (ICESC)*, pp. 738–743, IEEE, July 2023.

[53] A. Singh, S. K. Rasania, and K. Barua, "Inventory control: Its principles and application," *Indian Journal of Community Health*, vol. 34, pp. 14–19, March 2022.

[54] T. Limsakul and S. Taladgaew, "A survey of modeling the healthcare inventory for emerging infectious diseases," in *International Conference on Intelligent Computing and Optimization*, (Cham), pp. 404–413, Springer, April 2023.

[55] B. Balkhi, A. Alshahrani, and A. Khan, "Just-in-time approach in healthcare inventory management: Does it really work?," *Saudi Pharmaceutical Journal*, vol. 30, pp. 1830–1835, December 2022.

[56] S. Mankazana and S. C. Mukwakungu, "The impact of just-in-time (jit) in inventory management system and the supplier overall performance of south african's bed mattress manufacturing companies," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 239–249, 2018.

[57] H. Maraşlı, R. S. Halis, and M. F. Halis, "Lean medical inventory management in hospitals," *Journal of Academic Value Studies*, vol. 3, no. 8, pp. 16–28, 2017.

[58] A. D. Smith, "Exploring strategic partnering in supply chain management: Case study of successful practices," in *Supply Chain Management: Practices, Applications and Challenges*, Nova Science Publishers, 2016.

[59] J. Niemsakul, S. M. Islam, D. Singkarin, and T. Somboonwiwat, "Cost-benefit sharing in healthcare supply chain collaboration," *International Journal of Logistics Systems and Management*, vol. 30, no. 3, pp. 406–420, 2018.

[60] U. Praveen, G. Farnaz, and G. Hatim, "Inventory management and cost reduction of supply chain processes using ai based time-series forecasting and ann modeling," *Procedia Manufacturing*, vol. 38, pp. 256–263, 2019.

[61] S. T. Khorasani, J. Cross, R. Feizi, and M. S. Islam, "Application of lean tools in medication ordering systems for hospital," in *IIE Annual Conference Proceedings*, pp. 1145–1150, Institute of Industrial and Systems Engineers (IISE), 2017.

[62] S. S. Kessy, G. L. Salema, and Y. Simwita, "Lean thinking in medical commodities supply chains: Applicability and success factors for tanzanian health supply chains," *Journal of Humanitarian Logistics and Supply Chain Management*, vol. 14, pp. 105–117, January 2024.

[63] D. Dobrzykowski, "Understanding the downstream healthcare supply chain: Unpacking regulatory and industry characteristics," *Journal of Supply Chain Management*, vol. 55, pp. 26–46, April 2019.

[64] D. Elmuti, G. Khoury, O. Omran, and A. S. Abou-Zaid, "Challenges and opportunities of health care supply chain management in the united states," *Health Marketing Quarterly*, vol. 30, pp. 128–143, April 2013.

[65] H. Leite, S. Williams, Z. Radnor, and N. Bateman, "Emergent barriers to the lean healthcare journey: Baronies, tribalism and scepticism," *Production Planning & Control*, vol. 35, pp. 115–132, January 2024.

[66] G. M. Tetteh, S. Jagtap, S. Gupta, R. Raut, and K. Salonitis, "Challenges to lean 4.0 in the pharma supply chain sustainability," in *International Conference on Flexible Automation and Intelligent Manufacturing*, (Cham), pp. 316–323, Springer, June 2023.

[67] S. T. Khorasani, J. Cross, and O. Maghazei, "Lean supply chain management in healthcare: A systematic review and meta-study," *International Journal of Lean Six Sigma*, vol. 11, pp. 1–34, January 2020.

[68] D. Adebanjo, T. Laosirihongthong, and P. Samaranayake, "Prioritizing lean supply chain management initiatives in healthcare service operations: A fuzzy ahp approach," *Production Planning & Control*, vol. 27, pp. 953–966, September 2016.

[69] F. Centauri, P. Mazzocato, S. Villa, and M. Marsilio, "System-wide lean implementation in health care: A multiple case study," *Health Services Management Research*, vol. 31, pp. 60–73, May 2018.

[70] T. S. Ilangakoon, S. K. Weerabahu, P. Samaranayake, and R. Wickramarachchi, "Adoption of industry 4.0 and lean concepts in hospitals for healthcare operational performance improvement," *International Journal of Productivity and Performance Management*, vol. 71, pp. 2188–2213, June 2022.

[71] H. Woodward-Hagg and I. Bar-On, "Large system transformation within healthcare organizations utilizing lean deployment strategies," in *IIE Annual Conference Proceedings*, pp. 458–467, 2014.

[72] M. Dorval and M.-H. Jobin, "A conceptual model of lean culture adoption in healthcare," *International Journal of Productivity and Performance Management*, vol. 71, pp. 3377–3394, November 2022.

[73] P.-L. Fournier, M.-H. Jobin, L. Lapointe, and L. Bahl, "Lean implementation in healthcare: Offsetting physicians' resistance to change," *Production Planning & Control*, vol. 34, pp. 493–505, April 2023.

[74] A. Erthal, M. Frangeskou, and L. Marques, "Cultural tensions in lean healthcare implementation: A paradox theory lens," *International Journal of Production Economics*, vol. 233, p. 107968, March 2021.

[75] A. Bonamigo, P. M. Bernardes, L. F. Conrado, and R. D. Calado, "Optimizing patient flow in emergency care units and lean healthcare," in *Innovation, Strategy, and Transformation Frameworks for the Modern Enterprise*, pp. 167–185, IGI Global, 2023.

[76] R. Patri and M. Suresh, “Factors influencing lean implementation in healthcare organizations: An ism approach,” *International Journal of Healthcare Management*, vol. 11, pp. 25–37, January 2018.

[77] M. Chmielewska, R. Łotek Wąckowska, S. Brzozowski, Z. Tytko, K. Dziok-Dmowska, and T. Hermanowski, “The capacity to implement lean management in the healthcare system in poland–results of a public consultation,” *Medycyna Pracy*, vol. 74, no. 1, pp. 1–8, 2023.

[78] T. K. Régis, L. C. Santos, and C. F. Gohr, “A case-based methodology for lean implementation in hospital operations,” *Journal of Health Organization and Management*, vol. 33, pp. 656–676, October 2019.

[79] S. Chakraborty and J. A. Gonzalez, “An integrated lean supply chain framework for us hospitals,” *Operations and Supply Chain Management: An International Journal*, vol. 11, no. 1, pp. 1–13, 2018.

[80] S. Abedi, S. Kwon, and S. W. Yoon, “Healthcare and pharmaceutical supply chain automation,” in *Springer Handbook of Automation* (S. Y. Nof, ed.), pp. 1289–1308, Cham: Springer, June 2023.

[81] S. T. Khorasani, O. Maghazei, and J. A. Cross, “A structured review of lean supply chain management in health care,” in *Proceedings of the International Annual Conference of the American Society for Engineering Management*, (Huntsville), pp. 1–10, ASEM, October 2015.

[82] A. M. Almutairi, K. Salonitis, and A. Al-Ashaab, “Assessing the leanness of a supply chain using multi-grade fuzzy logic: A health-care case study,” *International Journal of Lean Six Sigma*, vol. 10, pp. 81–105, March 2019.

[83] N. Alemsan, G. Tortorella, C. M. Taboada Rodriguez, H. Balouei Jamkhaneh, and R. M. Lima, “Lean and resilience in the healthcare supply chain–a scoping review,” *International Journal of Lean Six Sigma*, vol. 13, pp. 1058–1078, September 2022.