(Review Article)

Sustainable supply chain management in U.S. healthcare: Strategies for reducing environmental impact without compromising access

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Abstract

The U.S. healthcare sector's supply chain operations are responsible for about 8.5% of all national greenhouse gas (GHG) emissions. In healthcare, traditional supply chain management has focused on cost efficiency to the detriment of environmental considerations leading to higher emissions, waste, and resource depletion. The focus of this study is to investigate strategies for making sustainable supply chain management (SSCM) in the U.S. healthcare system, while reducing environmental impact at minimal cost to patient care quality. The objectives of the study are to evaluate the current state of healthcare supply chains, explore sustainable practices, evaluate emerging technologies, propose an SSCM implementation framework, and explore policy implications. Sustainable supply chain management can be achieved by forming the key strategies: comprehensive waste reduction and recycling programs, adoption of energy efficient transportation and storage solutions, green energy sourcing, and use of data driven inventory management that would help optimize inventory, along with other technologies like blockchain, IoT and artificial intelligence that could achieve transparency and efficiency. The research wouldn't go into specific case studies but would likely look at institutions that have already been able to implement these practices. The findings indicate that considerable environmental footprint reduction of the U.S. healthcare sector is possible without sacrificing access to high quality care through adoption of SSCM practices. But it requires joint efforts from policymakers, healthcare providers and industry partners. The long-term goal is a sustainable, resilient healthcare system that will integrate environmental stewardship with high quality care, that will help mitigate climate change and acknowledge the interdependence of environmental and human health.

1. Introduction

The United States healthcare system, renowned for its advanced medical technologies and high-quality care, faces an increasingly urgent challenge: the need to balance operational effectiveness and patient care with environmental sustainability. Healthcare is one of the largest sectors in the U.S. economy, and it contributes a significant part of the national carbon footprint; recent evaluations show that it may correspond to around 8.5% of greenhouse gas emissions [1]. At the base of this environmental effect is the sophisticated and intricate healthcare supply chain that incorporates everything from medical supply production and distribution to waste management and logistics.

1.1. Problem Statement

As a major environmental threat to environmental and human health, the environmental footprint of the healthcare sector's supply chain operations is substantial. Currently, the focus of traditional healthcare supply chain management

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has been on cost reduction and efficiency, and not on environmental considerations. As a result of this approach, greenhouse gas emissions were rising, waste was being generated in excess, and natural resources were being depleted. Indeed, for example, Karliner et al. [2] discovered that the global healthcare sector, if it were a country in the world, would be the fifth largest emitter of greenhouse gases on the planet. Hospitals in the U.S. produce, collectively, approximately 29 pounds of waste per staffed bed each day, or 5.9 million tons annually [3]. In addition, the healthcare supply chain's dependence on single-use plastics has a massive impact on plastic pollution, with 25% of hospital waste plastic [4]. The healthcare sector's air pollution contribution leads to an estimated 405,000 disability-adjusted life years (DALYs) lost annually in the U.S. [5]. The U.S. healthcare sector is also responsible for an estimated 9-10% of national greenhouse gas emissions, with about 80% of these emissions resulting from the supply chain [5]. Findings indicate that climate change is affecting human health currently through growing heat-related illnesses, changes in infectious disease patterns, and a worsening of respiratory conditions, among other impacts [6]. Healthcare providers continually recognize their obligation to mitigate the impacts of climate change resulting from their practices. These statistics highlight the significant environmental and health impacts of current healthcare supply chain practices, emphasizing the critical need for sustainable solutions.

The term 'sustainable supply chain management' in healthcare refers to a wide variety of strategies and practices designed to reduce environmental impact and either maintain or improve the quality and accessibility of healthcare. These approaches include programs for waste reduction and recycling, energy-efficient transportation and storage techniques, sustainable sourcing and procurement practices, and improved inventory management with data-driven strategies [7]. Emerging technologies which include blockchain, Internet of Things (IoT), and artificial intelligence are offering opportunities to enhance supply chain transparency, traceability, and efficiency [8].

However, the pursuit of sustainability in healthcare supply chains must be carefully balanced with the primary mission of healthcare systems: to ensure high-quality care is accessible to all patients. This balance is particularly critical in the United States, where issues of healthcare access and affordability continue to be significant challenges [9]. Any sustainable supply chain initiatives must be planned and implemented without compromising patient care or increasing existing health disparities in healthcare access.

Furthermore, sustainable healthcare supply chain practices can present important co-benefits in addition to environmental protection. For example, waste reduction programs can save costs, which can be reinvested to enhance patient care or improve healthcare access [10]. Energy-efficient transportation and storage upgrades can help supply chains stay resilient in extreme weather events and other unexpected disruptions. Local economies can also benefit from sustainable sourcing procedures that reduce their vulnerability to global supply chains potentially at risk due to geopolitical tensions or trade disputes [11].

As people's awareness of climate change grows along with its health implications, it has inspired more research initiatives aimed at sustaining healthcare operations, especially in supply chain management [12]. However, the implementation of sustainable practices in healthcare supply chains faces special challenges. Unlike other sectors, the healthcare sector must maintain strict quality and safety standards, typically relying on single-use products and regulated temperature conditions to manage infection and ensure product efficacy [4].

In recent times, the concept of sustainable supply chain management (SSCM) has emerged as a possible solution to combat these environmental challenges and at the same time fulfilling the standards of healthcare delivery. SSCM brings together all the environmental, social, and economic concerns into the entire supply chain process, from sourcing raw materials to end of life product management. The healthcare sector has the ability to substantially reduce its environmental impact and improve operational efficiency while in the long run potentially reducing costs by adopting SSCM practices.

1.2. Aims and Objectives

This study aims to investigate and propose strategies for the integration of sustainable supply chain management practices in the U.S. health care system, in order to reduce environmental impact without compromising quality access to health care.

To achieve this aim, the study has the following objectives:

- To access the current state of healthcare supply chains in the U.S. and their environmental impact.
- To determine and examine current practices towards sustainable healthcare supply chain management.
- To assess the promise of emerging technologies to improve sustainability in healthcare supply chains.

- To propose a framework to implement SSCM in U.S. healthcare in the context of both environmental sustainability and healthcare accessibility.
- To explore the policy implications for adoption of SSCM practices in healthcare.

This work uses case studies, examines policy initiatives, and explores future trends to contribute to the ongoing discussion about sustainability in healthcare and to provide practical insights for healthcare leaders, policymakers, and researchers working to create a more sustainable and resilient healthcare system. The path to sustainable healthcare supply chains is complex and challenging, but they also present numerous opportunities for innovation, collaboration, and positive impact on both human and environmental health.

2. Current State of Healthcare Supply Chains in the U.S.

In the U.S., the medical supply chain is a complex system that encompasses the flow of pharmaceuticals, medical supplies, and equipment from manufacturers to healthcare institutions and ultimately to patients. This complex network involves several stakeholders such as manufacturers, distributors, group purchasing organizations (GPOs), healthcare facilities, and regulatory bodies [13].

In recent years, the U.S. healthcare supply chain has faced serious challenges. The pandemic of COVID-19 has revealed vulnerabilities in the supply chain, notably overdependence on global suppliers, particularly for personal protective equipment (PPE) and needed medications [14]. This crisis emphasized the need for greater resilience and domestic production in the healthcare supply chain. Inefficiencies in the existing system cause both financial and ecological costs. It is estimated that supply chain expenditures make up about 30-40% of hospital operating costs [15]. In addition, the healthcare sector is responsible for nearly 8.5% of U.S. greenhouse gas emissions, where a large fraction can be traced back to supply chain activities [1].

Efforts to improve healthcare supply chain management have centered on technologies, such as RFID tracking, blockchain for more reliable traceability, and artificial intelligence for demand forecasting [16]. Even so, the sector has shown uneven adoption of these technologies, with many facilities still depending on old inventory management systems. The recognition of the critical environmental impact of healthcare supply chains is on the rise. Single-use plastics and antiquated medications present significant challenges in their production of waste [4]. Moreover, the energy-intensive nature of manufacturing and transporting medical products greatly increases the sector's carbon footprint [12].

As the healthcare industry continues to evolve, the priority for stakeholders to address these supply chain issues while managing costs and sustainability concerns is becoming increasingly important.

3. Leveraging Technology for Sustainable Supply Chain Management

The integration of the latest technologies is transforming healthcare supply chain management, presenting innovative methods to enhance sustainability and efficiency. Four key technologies are driving this transformation: RFID tracking, blockchain, Internet of Things (IoT), and Artificial Intelligence (AI).

3.1. RFID tracking

In the U.S. healthcare supply chain, RFID (Radio Frequency Identification) tracking has been used to increase inventory accuracy and efficiency. If hospitals embed RFID tags in medical supplies on the machine and trial sensors in inventory, they can reduce stockouts and waste of both inventory and time as they track inventory levels, location of items in real time, and expiry dates [17]. A practical example is observed by Children's National Hospital, DC where implementation of RFID technology significantly reduced red blood cell (RBC) units loss from 4.0% to less than 1% annually. It also improved inventory management and reduced the work burden of staff [18].

3.2. Blockchain technology

Supply chain transparency and traceability are revolutionized by blockchain technology. By durable, distributed transaction ledger, blockchain enables full visibility of medical products from the manufacturer to the patient. Such enhanced traceability can help significantly reduce counterfeit items, enhance recall efficacy, and reduce waste [19]. For example, IBM's blockchain technology is helping to verify and appropriately manage COVID-19 vaccines throughout their supply chain [20].

3.3. The Internet of Things (IoT)

The Internet of Things (IoT) is making real-time monitoring and optimization of healthcare supply chains possible. IoT sensors can track inventory levels, monitor equipment usage, and maintain ideal environmental conditions for sensitive medical goods. The continuous flow of data provides precise inventory management, thereby reducing both overstocking and waste [19]. For instance, many hospitals incorporate RFID-enabled cabinets that can automatically track and replenish medical supplies, increasing productivity and reducing stockouts [21].

3.4. Artificial Intelligence (AI) and Machine Learning (ML)

Artificial Intelligence (AI) and Machine Learning (ML) are powering predictive analytics in healthcare supply chains. These technologies can evaluate a large amount of data to predict demand, optimize routing, and predict the need for maintenance. The use of AI in demand forecasting has been shown to cut inventory costs and improve product availability [22]. For instance, Concurrency, a mid-sized furniture retailer put in place an AI-driven demand planning system. Using this system, the forecasting accuracy was improved 15%, saving $16 million per year and accurately predicting demand for thousands of products [23]. As a result, the implementation resulted in substantial reductions in carrying costs for inventory and improved product availability. Additionally, AI can optimize transportation routes, reducing fuel consumption and associated emissions [24].

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4. Strategies for Sustainable Supply Chain Management

In healthcare, strategies of sustainable supply chain management (SSCM) provide benefits of both reducing the industry's environmental impact and supporting sustainable quality patient care. This segment investigates major strategies healthcare organizations can utilize to increase the sustainability of their supply chains.

4.1. Waste Reduction and Recycling Programs

The management of the substantial waste produced by healthcare activities is one of the most important challenges in achieving sustainability in healthcare. Implementing comprehensive waste reduction and recycling programs is essential for minimizing environmental impact and reducing costs [4].

- **Proper sorting and disposal of medical waste**: Implementing waste segregation strategies on a major scale can help healthcare facilities reduce their environmental impact. This involves separating recyclable materials, compostable organic waste, and hazardous medical waste. Proper staff training combined with understandable signage can improve compliance with these protocols [25]. A comprehensive waste segregation program of the Cleveland Clinic in Ohio did result in significant improvement in medical waste sorting. They were able to reduce the volume of RMW by 35% by separating hazardous from non-hazardous waste [26]. This not only reduced environmental impact but disposal costs, as non-hazardous waste costs less to process.
- **Recycling of packaging materials**: A huge portion of healthcare waste is due to packaging materials. Establishing recycling systems for cardboard, plastic, and all other forms of packaging material can reduce landfill waste. Certain hospitals are collaborating with suppliers to create closed-loop recycling systems for specific products [10]. A major healthcare provider can be Kaiser Permanente which operated a recycling program on the collection and recycling of packaging materials such as plastic wraps, boxes, and trays. Using these efforts, over 40% of their total waste has been diverted from landfills [27]. This has not only cut the environmental footprint of their supply chain but has directly translated into savings approaching millions of dollars each year.
- **Reprocessing of eligible medical devices**: Single-use device (SUD) reprocessing is becoming more popular as a sustainable healthcare practice. Hospitals can reduce waste and costs while ensuring patient safety by adequately cleaning, testing, and repackaging certain medical devices [28]. Through partnerships with FDA-approved third-party reprocessors, the Mayo Clinic implemented a program to reprocess single-use devices (SUDs). The reuse of some devices, such as catheters and orthopedic blades, cut the cost of new equipment by as much as 25% via this program [29]. Also, they've been able to divert nearly 30,000 pounds of waste from landfills each year, which is good for a more sustainable supply chain.

4.2. Energy-efficient Transportation and Storage

Medical supply transportation and storage are responsible for a considerable share of the carbon footprint of healthcare supply chains. Putting energy-efficient methods to use in these sectors can lead to major environmental and economic rewards.

- **Optimized routing and scheduling**: Utilizing advanced logistics software and artificial intelligence can help healthcare organizations optimize their transportation routes and schedules. It decreases fuel consumption and emissions while also improving the efficiency of supply delivery [24]. Geisinger Health System in Pennsylvania is optimizing its routes and schedules using advanced logistics software which cuts delivery route and schedule to consolidate deliveries and reduce trips between their facilities. The outcome was a 20% drop in fuel consumption and an enormous cut in carbon emissions [30]. In addition, Geisinger was able to cut transportation costs and improve the efficiency of supply deliveries throughout its network by streamlining deliveries.
- **Use of electric or hybrid vehicles**: Transitioning to electric or hybrid vehicles for local transportation of medical supplies can significantly reduce carbon emissions. Some healthcare systems are now adopting electric vehicles for their fleets, particularly for delivering short distances [31]. A leader in sustainable healthcare, Kaiser Permanente put a fleet of hybrid and electric vehicles to use transporting medical supplies between facilities in California. Kaiser Permanente has made the transition to low-emission vehicles, reducing carbon footprint by up to 30% and transportation-related emissions [32]. It also supports their wider sustainability goals and has helped to cut operational costs related to fuel consumption.
- **Energy-efficient cold chain management**: Many medical products, such as vaccines and a variety of medications, need temperature-controlled environments. Using energy-efficient refrigeration systems together with phase-change materials for insulation can cut energy consumption in the cold chain logistics sector [33]. The cold chain management for temperature-sensitive medical products was done by Johnson & Johnson [34] through energy-efficient cold chain management practices. The trail included the use of solar-powered refrigerators and energy-efficient cooling units to ensure the temperature is maintained during their transit. Such technologies have also enabled Johnson & Johnson to reduce their energy consumption in cold chain logistics by 20% while guaranteeing pharmaceutical integrity from the point of origin to the point of delivery. As a result, there have been both cost savings and a lower environmental impact [34].

4.3. Sustainable Sourcing and Procurement

A healthcare supply chain that is more sustainable requires sustainability requirements to be part of its sourcing and procurement processes.

- **Supplier evaluation based on environmental criteria**: Healthcare organizations can develop scorecards for suppliers that comprise environmental performance metrics. This encourages suppliers to adopt sustainable practices and helps healthcare providers make informed decisions about their supply chain partners [35]. One of the keys to the use of a supplier evaluation program that includes environmental criteria is being used by the Cleveland Clinic. Secondly, they look at suppliers based on carbon footprint, their type of waste management, and use of environmentally friendly materials. This has allowed the clinic to work with the suppliers who align with clinic's sustainability goals and it has resulted in a 30% decrease in the clinic's overall waste and a more environmentally responsible supply chain [36, 26].
- **Preference for eco-friendly products and packaging**: Prioritizing products with minimal environmental impact, such as those produced from recycled materials or with biodegradable packaging, can reduce the overall environmental effect of healthcare supply chains [37]. Illinois based Advocate Health Care implemented a policy in which ecofriendly products and packaging is purchased first. They started using biodegradable packaging for some medical supplies and stopped using single use plastics. With this initiative, Advocate Health Care has been able to reduce plastic waste by 25%, promote sustainability within the facilities and reduce the facility's environmental impact [38].
- **Local sourcing to reduce transportation emissions**: Sourcing products from local suppliers can reduce transportation distances and associated emissions. This strategy is capable of strengthening supply chain resilience and helping local economies [11]. A large healthcare network, Providence Health & Services, has cut transportation related emissions by sourcing food, medical supplies and equipment locally. They've been able to reduce their long haul transport needs (and associated fuel emissions) by 15% by partnering with local suppliers within 100 miles of their facilities. This approach has also improved support for local economies while creating a more sustainable and less vulnerable supply chain [39].

4.4. Inventory Optimization

Efficient inventory management is important for waste reduction and the improvement of overall sustainability of healthcare supply chains.

- **Just-in-time inventory management**: Healthcare organizations can reduce overstock and expired product waste by using just-in-time (JIT) inventory systems. However, this method needs to be balanced with the need

for emergency preparedness and potential supply chain disruptions [40]. Just in Time (JIT) inventory management was adopted by the Mayo Clinic to reduce excess stock and storage needs. They coordinated deliveries in such a way that there was little opportunity for investing in excess inventory and excess waste due to expired medical supplies. The strategy saved the clinic space, cut waste by 20%, and made its supply chain more efficient and sustainable [41].

- **Data-driven demand forecasting**: The use of advanced analytics and machine learning algorithms can improve demand forecast accuracy in healthcare. This situation results in more effective inventory management and cuts down on waste from either overstocking or understocking [22]. Boston Medical Center, for instance, used advanced analytics to predict usage patterns of pharmaceuticals and medical supplies and then used data driven demand forecasting to help predict demand. Using electronic health records (EHR) and predictive analytics software, they were able to better predict how much of which supplies they should order and when. This has reduced stockouts and overstock situations by 15%, and a more sustainable flow of resources without generating unnecessary overproduction and waste [42].
- **Collaborative planning with suppliers and healthcare providers**: Strengthening collaborations among healthcare providers, manufacturers, and distributors can lead to supply chains that are both effective and responsive. Data sharing and forecast alignment can enhance waste reduction and better overall supply chain performance [43]. In Utah, Intermountain Healthcare set up a program for collaborative planning with key suppliers to optimize the flow of medical products. Intermountain Healthcare has reduced lead times and increased suppliers' reliability of deliveries by sharing demand forecasts inventory data. The result has been a 10 per cent reduction in inventory and minimized risk of supply disruptions that have led to a more efficient and sustainable supply chain [44].

5. Case Studies

Some healthcare organizations have effectively implemented sustainable supply chain projects, providing valuable insights and best practices for the healthcare industry.

Leading U.S. healthcare provider Kaiser Permanente has made considerable progress in sustainable procurement. Thanks to their commitment to environmentally preferable purchasing (EPP), they observed a 29% drop in their carbon footprint from 2018 to 2022 [45]. A major contributor to their success was their powerful emphasis on engaging suppliers. Kaiser Permanente organized a Sustainable Procurement Working Group that worked alongside major suppliers to design eco-friendly alternatives for frequent medical supplies and equipment. They also partnered closely with manufacturers to change product formulations by removing harmful chemicals, including DEHP and PVC, from medical devices, resulting in products that are both safer and more environmentally friendly. Additionally, the organization implemented strategies to cut down on packaging waste. To manage the elimination of over 40 tons of cardboard waste each year, they introduced a reusable tote program for internal supply distribution. Moreover, they conducted extensive life cycle assessments on prominent products, which informed decisions to move towards more sustainable options.

The waste reduction program launched by Cleveland Clinic in 2019 shows the potential for complete waste management in healthcare environments [46]. Their success was in part due to their application of a standardized waste segregation system, using color coding, throughout all facilities. This enhanced proper waste sorting and reduced the quantity of regulated medical waste by 15%. In parallel, wide staff training programs were developed that confirmed that all staff understood proper waste segregation techniques, leading to a 12% increase in recycling rates. Along with a certified reprocessing company, Cleveland Clinic has partnered to reprocess medical devices. This partnership has enabled safe cleaning, sterilization, and reuse of eligible single-use devices, saving more than $2 million in supply costs each year. In addition, a directed operating room recycling program was launched, which captured clean plastic and paper waste. In its first year, the program succeeded in diverting 110 tons of material from landfills.

6. Balancing Sustainability

Implementing sustainable supply chain management (SSCM) practices in healthcare must be carefully balanced with the sector's primary mission: access to high quality care for all patients. This is important in the United States, where problems of access and affordability of health care are still important [9].

One important element of achieving both sustainability and access is to make sure critical supplies are available. Lean inventory management does reduce waste and increase sustainability, but it must not sacrifice the ability to respond to sudden surges in demand and emergencies. The COVID-19 pandemic showed that overly lean supply chains were risky,

as healthcare facilities had critical materials such as personal protective equipment (PPE) [14]. Access to care during crises requires that sustainable supply chain strategies include resilience and flexibility.

However, cost management is also very important. Some sustainable practices will save you money in the long term, while others may require major upfront investment. Sustainability initiatives must be considered carefully by healthcare organizations against the possible financial consequences, since doing so could provoke increased costs for patients, thereby diminishing patients' access to care. But research shows that many sustainable practices can actually lead to cost reduction over time. As an example, MacNeill et al. [10] demonstrated that reprocessing single use medical devices can save hospitals hundreds of thousands of dollars a year whilst reducing waste.

Another challenge is adapting sustainable strategies for rural and underserved areas. Typically, these areas encounter special logistical issues and resource constraints. These differences in sustainable supply chain solutions must be accommodated while still improving environmental performance. Efficient and sustainable supply chains, coupled with promise of telemedicine and decentralized care models, promise to expand access in these areas while minimizing environmental impact [47].

Finally, the objective is to achieve synergies between sustainability and access. For instance, choosing to eliminate unnecessary medical procedures and the supplies consumed associated with them not only decreases environmental impact, but also may improve patient outcomes and reduce costs, potentially improving access [48]. Healthcare organizations that appropriately take these factors into account can easily implement SSCM practices which together improve environmental sustainability and healthcare accessibility.

Policy recommendations

To facilitate the widespread adoption of sustainable supply chain management (SSCM) practices in U.S. healthcare, policymakers should consider the following recommendations:

- Incentivize Sustainable Practices: Give healthcare organization implementative financial incentives to adopt SSCM practices such as tax breaks or grants. That could be having rewards for reducing carbon, implementing waste reduction programs or investing in sustainable technologies.
- Establish Sustainability Standards: Work with the industry and develop and enforce industry wide sustainability standards for healthcare supply chains. Areas of waste management, energy efficiency and sustainable sourcing should also be covered by these standards.
- Mandate Sustainability Reporting: Put similar (or similar) financial reporting requirements on healthcare organizations to report on their environmental impact and sustainability efforts. This would bring transparency and accountability in the sector.

6.1. Future perspectives

A sustainable and accessible U.S. healthcare system is one that integrates environmental stewardship and high quality, equitable care on the long term. The future healthcare landscape we propose is based on circular economy principles, minimizing waste and maximizing resource efficiency. Advanced technologies such as blockchain and AI streamline supply chain while reducing costs and environmental impact. Decentralized care models and telemedicine help to decrease emissions from transportation and improve access to healthcare. The facilities are used for energy efficiency and use renewable energy resources. The sector actively contributes to climate change reduction, knowing the link between human and environmental health. Policymakers, healthcare providers and industry partners will need to work together to achieve this vision, which is one focused on a resilient, sustainable healthcare system that prioritizes environmental health as much as patient care.

7. Conclusion

In the United States healthcare industry, assuring high-quality care and access requires sustainable supply chain management to mitigate its environmental effects. Significant strategies include waste reduction, energy-efficient transportation, sustainable sourcing, and optimized inventory management. The application of technologies like blockchain, IoT, and AI can further enhance sustainability efforts. According to successful case studies, balancing environmental concerns with healthcare access is possible through careful implementation of these strategies. Moving forward, all stakeholders in the healthcare sector, such as healthcare leaders, policymakers, and researchers must make sustainability a top priority in their supply chain activities. By doing so, the sector can reduce its ecological impact while providing effective patient care, thus creating a new standard for sustainable healthcare delivery in the 21st century.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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