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Artificial Intelligence in Healthcare Supply Chains: Enhancing Resilience and Reducing Waste

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ABSTRACT

Efficient inventory management is crucial in the healthcare industry to ensure the availability of essential medications and medical supplies while minimizing wastage and reducing costs. This study explores the role of Artificial Intelligence (AI) in optimizing inventory management and enhancing supply chain resilience within healthcare settings. By leveraging AI-driven solutions, healthcare organizations can improve demand forecasting, streamline supply chain operations, and minimize medication waste. Incorporating AI technologies, including machine learning and predictive analytics, allows for more precise demand forecasting, minimizes the chances of both overstocking and stockouts, and enhances overall operational efficiency. The research further examines the theoretical frameworks of Resource-Based View (RBV) and Systems Theory to highlight the strategic and systemic benefits of AI in healthcare inventory management. Empirical evidence from recent studies underscores the potential of AI to transform healthcare supply chains, promoting sustainability and improved patient care. This study employs a survey research design targeting healthcare professional in the United States, with data analyzed through machine learning algorithms to identify key patterns and insights. Ethical considerations, including data privacy and informed consent, are meticulously adhered to, ensuring the integrity of the research process.

Keywords: *Artificial Intelligence, Inventory Management, Healthcare Supply Chain, Waste Reduction, Supply Chain Resilience, Demand Forecasting, Machine Learning, Predictive Analytics, Resource-Based View, Systems Theory.*

1. INTRODUCTION

In the healthcare industry, efficient inventory management is critical to maintaining the availability of necessary medications and medical supplies while reducing expenses and waste [1]. This study examines how important inventory management is to raise operational effectiveness, boosting patient care, and guaranteeing adherence to legal requirements. The research seeks to highlight best practices and creative ideas that help enhance inventory operations by examining existing practices and identifying difficulties. Healthcare providers that want to offer high-quality treatment at a reasonable cost can find great insights from knowing how inventory management affects the healthcare supply chain.

Efficient inventory management is essential in the healthcare industry, as any disruption can impede hospital operations. Therefore, hospitals must keep a stable and well-stocked inventory because the lives of many patients rely on it. Sudden requirements and that

too of a macro nature inside a hospital can only be fulfilled by having an effective hospital inventory management system in place [2].
The healthcare business depends heavily on pharmaceuticals because of the high prices of goods, storage, and control needs. Consequently, one of the main goals of healthcare supply chain management (HSCM) is to optimize pharmaceutical inventories. In this regard, maintaining the performance efficiency of the healthcare supply chain depends on efficient inventory management [3].
In the healthcare supply chain, consignment inventory plays a vital role by providing medical institutions with necessary items at the lowest possible carrying cost. Because medical instruments are vital, efficient product management is essential to the smooth running of the business. Effective management of consignment inventory reduces the possibility of shortages or overstocking while also improving patient care [4].
Several medical goods' disposability and perishability have become big issues for healthcare supply chain management. Inventory management is closely related to the existing management techniques and disputes between various parties involved in health care supply chains [5].
The World Health Organization (WHO) defines medical waste as the use of pharmaceuticals that are no longer needed and should be disposed of properly, such as unused, expired, spilled, or contaminated drugs [6]. Research carried out in Addis Ababa, Ethiopia, found that insufficient storage space, unclean stores, and product misarrangement were examples of inefficient storage practices. Comparably, different research conducted in Eastern Ethiopia brought to light problems with misaligned products, a lack of shelves, and space constraints [7].
When it came to vital medications, the rate of expiration was greatest.
While there are sufficient instruments for quantification and demand planning, none of them are specifically designed with health workers without professional training in medicine supply management in mind. This means that managing medications is not limited to only pharmacists [8].
Medication wastage due to medication expiration is a worldwide issue. According to estimates, waste rates in the US and Switzerland are 16% and 29%, respectively, costing the countries more than $1 billion [9] and $436 million [10]in lost revenue annually. Research on the financial loss resulting from expired medications is scarce in underdeveloped nations. Even so, Mwesige (2006) projected that Uganda lost at least $550,000 in income in 2006 as a result of medication that had expired. Despite the lack of particular published cost statistics for South Africa, the Viennese Sickness Fund estimated in 2014 that the nation possessed $8.8 million worth of expired medications [10].
Significant wastage occurs due to medicines expiring, which can be mitigated through better management and efficient inventory coordination. For instance, between July 2007 and June 2008, medicines worth $66,000 expired across 41 hospitals in the Limpopo province, representing approximately 0.07% of monthly pharmaceutical expenditures [11]. Various factors across different levels of the medicine supply management (MSM) cycle contribute to medicine expiration, including those at the manufacturer, supplier, organization, and user levels. All these levels play a role in ensuring the availability of medicines to patients. However, the risk of medicines expiring increases with longer supply chains [12].
Inventory management is essential for achieving the goals of efficient supply chains, controlling costs, and delivering to customers with minimal delays and goes hand in hand with the supply chain [13].
Planning and managing an industry's inventory are the main focus of inventory management, which is a crucial aspect of supply chain management. It covers things like figuring out how much material is needed at different stages of the supply chain, how often orders should be placed, and safety stock levels. Inventory visibility, forecasting, management, lead times, shipping costs, inventory valuation, future inventory price forecasting, physical space availability, quality control, returns and defective goods, and demand forecasting are also included [14].
Thanks to the improved capabilities of contemporary computer technology, advances in artificial intelligence (AI) technologies are making inventory management a more sophisticated operation. AI's core subfields of machine learning (ML) and deep learning (DL) are vital to this development. An increasing body of research suggests that ML and DL techniques—which can quickly assess vast, heterogeneous data sets and increase demand forecasting accuracy—are becoming more and more popular. Inventory management processes become more flexible and efficient when AI approaches are included. This also lowers operating costs, gives consumers faster response times, and produces more contextual information [15].
Although supply chain management and demand planning have long been served by specialist analytics systems, recent years have seen a major technical turning point. Businesses can handle data and automate processes at a size, speed, and sophistication that surpasses conventional analytics thanks to the maturation of AI and machine learning technology. Businesses may now detect changes in data in real time and anticipate developing market trends that might mean the difference between profit and loss thanks to machine learning and artificial intelligence. Along with enhancing forecast accuracy and speeding up supply chain executions, it also drastically simplifies the demand planning process by cutting out non-value-adding touchpoints, increasing process effectiveness, and fortifying the supply chain [16].

2. LITERATURE REVIEW

The use of modern technologies has resulted in substantial breakthroughs in inventory management. For a firm to succeed, effective inventory management is essential to have the right items in the appropriate amounts at the right times. In all businesses, efficient warehouse inventory management is critical to the supply chain process. Ensuring product availability in the right quantities at the right times is the main goal of a well-organized inventory management system. This improves customer satisfaction, minimizes stockouts, and lowers the expenses related to excess inventory [17].AI's ability to identify patterns and trends in data makes it effective in inventory management. By analysing past sales data, consumer behaviour, and market trends, AI helps businesses predict demand changes, manage stock levels, and understand inventory needs. It also excels in predictive analytics, projecting future demand based on past data and market conditions. This proactive approach reduces stockouts, decreases inventories, and enhances operational effectiveness [1].

2.1. Artificial Intelligence in Inventory Management

The fast adoption of AI applications since the early 2010s has produced encouraging outcomes, but it has also raised questions about how work and company management will develop in the future. To improve their end-to-end supply chain processes, businesses are embracing AI more and more and investing in AI solutions. The literature on supply chains, it seems, is still developing in order to include modern AI techniques into its fundamental research [18].

A "one for one" policy, where each supply chain member places an order with its upstream supplier whenever an order is received from its downstream customer, is shown to be the optimal ordering policy in an environment where demand is deterministic and unsatisfied demand is penalized [19]. However, the uncertainty surrounding hospital demand for pharmaceutical products, which is related to patient volume and treatment protocols, makes this strategy much more difficult to find, and has led researchers to incorporate patient arrivals' stochasticity into the conventional inventory control models [20].

By employing artificial intelligence (AI) tools to detect inefficiencies, optimize transportation routes and pre-empt disruptions before they happen, AI can streamline supply chain operations. They provide information on the best inventory policy considering random fluctuations of demand, lead times and cost constraints in order to keep enough stock for certain product availability while reducing overstock. AI-driven inventory management solutions help save both time and energy, while also being more sustainable than conventional means.

2.2. Impact of AI on Reducing Medication Waste

Medical organizations may gain a lot by using AI to optimize inventory levels and increase the accuracy of demand forecasts. Artificial intelligence (AI)-powered analytics can accurately forecast the number of medications and medical supplies that are needed in store, minimizing surplus inventories. By doing this, storage expenses are decreased and the financial burden of keeping unsold or excess inventory is avoided. AI can also predict demand precisely, which prevents the stockpiling of out-of-date or expired medical supplies and cuts down on waste. This promotes sustainable procedures in the medical business and lowers markdown and disposal expenses. By guaranteeing the timely availability of necessary medical supplies, integrating AI into inventory management ultimately improves patient care, increases operational efficiency, and makes better use of available resources. Owing to unpredictability in market demand, pharmaceutical producers and healthcare supply chains frequently have to manage the risk of their products becoming outdated. Manufacturers typically sell surplus inventory to foreign markets before their products expire at discounted rates in order to lower this risk [21].

2.3. Ethical Considerations of AI in Healthcare

The General Data Protection Regulation (GDPR) and Genetic Information Non-discrimination Act (GINA) are crucial in ensuring data protection and privacy in the context of Artificial Intelligence-Driven Inventory Management (AI-DMI). GDPR mandates stringent measures for data handling within the EU, while GINA protects individuals from discrimination based on genetic health information. AI-DMI can reduce waste by accurately predicting medical supplies and pharmaceuticals, avoiding excess inventory and costs. Compliance with GDPR and GINA ensures AI systems maintain trust and adhere to legal standards, while leveraging AI for efficient operations. General Data Protection Regulation (GDPR) was first enacted by the European Union (EU), as it amended the privacy legislation in other countries, such as the US and Canada. According to these regulations, all personal data and the activities of foreign communities and companies are processed by the union-based data processor or controller in order to protect the information of natural persons with sufficient protection [22]. Employers are not allowed to make discriminatory choices based on an individual's genetic health information in the United States under the Genetic Information Non-discrimination Acts (GINA) [23].

2.4. Future of AI-Driven Inventory Management

The healthcare industry has been transformed by artificial intelligence (AI), which has affected many other industries as well. Artificial Intelligence has the capability to greatly enhance supply chain management for vaccine distribution within the West African healthcare sector, particularly in Ghana. It is clear that artificial intelligence (AI) can greatly increase efficiency and effectiveness by examining pertinent case studies, real-world examples of nations that have successfully integrated AI into their vaccine supply chain management, and the World Health Organization's (WHO) operations on vaccine distribution. Rwanda is one nation that has effectively integrated AI into its supply chain management for vaccines [24]. This method has decreased spoilage-related waste while also increasing access to vaccinations. The WHO also acknowledges the significance of effective vaccination campaigns. Their "Smart Vaccination Management System" (SVMS) is a platform that they have created in partnership with UNICEF and Gavi, the Vaccine Alliance. SVMS optimizes vaccine distribution based on population requirements and disease occurrence by leveraging AI technologies like machine learning and predictive analytics. This guaranties that immunizations are distributed fairly throughout nations [25].

Efficient vaccine governance must include real-time tracking of vaccine shipments, and AI technologies have shown to be effective tools for facilitating this process. Governments and healthcare institutions may efficiently handle supply chain issues, reduce waste, and guarantee the timely delivery of vaccinations by utilizing AI [26]. Through a variety of channels, AI can help with real-time tracking and monitoring of vaccination supplies. Shipment containers, for example, may incorporate smart sensors with AI algorithms to continually check temperature conditions. By monitoring temperature variations in real time, these sensors can stop vaccines from spoiling as a result of incorrect handling, storage, or transit [27].

2.5. Traditional Inventory Management Challenges in Healthcare

Healthcare organizations have several difficulties with traditional inventory management, especially with regards to waste control. Overstocking, medical supply expiry, and poor inventory tracking are all common outcomes of inefficiencies that result in significant waste and higher expenses. These problems put a burden on financial resources and delay the timely delivery of essential medical supplies, which eventually affects patient care. Improving healthcare supply networks' sustainability and efficiency requires tackling these long-standing issues.

Merchandise governance is essential to any company's effective operations as it ensures a sufficient amount of or a lack of goods on hand and lowers the danger of running out of stock and erroneous records. Every other business activity must manage its inventory [28]. The pace at which inventory is bought, consumed, and refilled is known as inventory turnover. The cost of the products is divided by the inventories for the same time period to get the inventory turnover ratio. Inventory turnover is one measure

of effective inventory management. "Inventory turnover" is a financial metric that quantifies the speed at which stock is moved over time [29].
The practice of keeping an eye on your healthcare system's stock, purchases, orders, payments, and other operations is known as healthcare inventory management. Healthcare organizations that administer basic care, buy and distribute drugs, or promote health items to patients must have an inventory management system [30]. Large hospitals' use of inventory management systems may help protect their healthcare system from monetary and material losses by keeping an accurate and up-to-date record of the goods and supplies. Research has shown that there is need for improvement in the basic quality control procedures, customer satisfaction, and waste elimination in healthcare facilities in underdeveloped countries [31].

2.6. Theoretical Review

In the healthcare sector, efficient inventory management is critical for minimizing waste and ensuring the availability of essential medical supplies. Leveraging Artificial Intelligence (AI) for inventory management presents a promising approach to tackling these challenges. To understand the strategic implications and systemic impact of AI-driven inventory management, this paper draws upon the Resource-Based View (RBV) and Systems Theory.

2.6.1. Resource-Based View (RBV) Theory

The Resource-Based View (RBV) theory provides a strategic lens through which we can examine the value of AI-driven inventory management. According to RBV, an organization’s internal resources and capabilities are pivotal for achieving and sustaining a competitive advantage. AI technology in inventory management exemplifies a valuable resource due to its potential to significantly enhance efficiency and reduce waste. For instance, AI algorithms can predict demand with high accuracy, optimize stock levels, and automate replenishment processes. These capabilities reduce the likelihood of overstocking and stockouts, thereby minimizing waste and ensuring critical supplies are always available.
Moreover, the implementation of sophisticated AI systems can be considered a rare capability within the healthcare sector. Not all healthcare organizations possess the technological expertise and resources to deploy AI-driven solutions effectively. This rarity adds to the competitive advantage for early adopters who can leverage AI to streamline their inventory management processes. AI-driven inventory systems can create inimitable efficiencies. The integration of AI into supply chain processes results in unique combinations of data analytics, machine learning, and domain-specific knowledge that are difficult for competitors to replicate. These systems also become non-substitutable assets, as the specific benefits they provide cannot be easily replaced by other technologies or processes.

2.6.2. Systems Theory

Systems Theory offers a complementary perspective by viewing the healthcare supply chain as a complex and interconnected system. Systems Theory emphasizes the importance of understanding the relationships and interactions between different components of a system to achieve overall efficiency and resilience. Applying Systems Theory to AI-driven inventory management highlights the interconnected nature of the healthcare supply chain. Each component, from suppliers and inventory systems to distribution networks and healthcare providers, plays a crucial role in the system's functionality. AI enhances this interconnectedness by providing real-time data and predictive analytics, which enable healthcare organizations to respond swiftly to changes in demand and supply conditions. This dynamic capability helps in identifying potential disruptions early and implementing corrective measures proactively.
While AI introduces feedback loops within the supply chain, these loops provide continuous data flow and insights, allowing for ongoing optimization and adjustment. For example, AI can analyze consumption patterns and predict future needs, which feeds back into the inventory management system to adjust procurement strategies accordingly. This continuous feedback enhances the overall resilience of the supply chain, making it more adaptable to unforeseen challenges, such as sudden surges in demand during a pandemic.

2.6.3. Integration of Theories

By integrating RBV and Systems Theory, we gain a comprehensive understanding of how AI-driven inventory management can transform healthcare supply chains. From the RBV perspective, AI is a strategic resource that provides a significant competitive advantage through its value, rarity, inimitability, and non-substitutability. Meanwhile, Systems Theory underscores the systemic impact of AI, highlighting its role in enhancing the efficiency and resilience of the interconnected supply chain components. Together, these theories elucidate that AI-driven inventory management is not only a powerful internal asset but also a critical enabler of systemic resilience. It reduces waste by optimizing inventory levels and ensures the robustness of the supply chain by providing real-time, actionable insights.

2.7. Empirical Review

[32] addresses the inefficiencies and high costs of current healthcare supply chains by proposing the use of artificial intelligence (AI) systems for mode selection to adapt to economic and public health changes. It combines economic, social, and environmental benefits to identify various healthcare supply chain modes using AI, specifically through a deep reinforcement learning algorithm. The simulation results demonstrate that AI-selected modes align closely with target modes, outperforming traditional methods. The study concludes that AI offers significant advantages for healthcare supply chain management, filling gaps in existing methods and providing practical and theoretical guidance for sustainable and intelligent decision-making in this field.
[33] examines the adoption of advanced technologies like AI and Industry 4.0 in healthcare supply chains (HSC), particularly in the context of emerging economies. Using Rough SWARA for ranking, the research identifies and prioritizes critical success factors (CSFs) for AI adoption. The results reveal that technological (TEC) factors are the most influential in adopting AI in HSC, followed by institutional/environmental (INT), human (HUM), and organizational (ORG) dimensions. This study underscores the significance of TEC factors and highlights the potential of AI and advanced technologies to address vulnerabilities in HSC, as exposed by events like the Covid-19 pandemic.
[34] explores the role of artificial intelligence techniques (AITs) in enhancing healthcare supply chain resilience (HSCR) amidst disruptions like COVID-19. It investigates how AITs can improve HSC adaptability and collaboration, using data from the Indian healthcare sector analyzed via partial least squares structural equation modeling (PLS-SEM). Findings indicate that AITs promote HSC adaptability and collaboration, both critical for HSCR. Additionally, supply chain dynamism (SCD) moderates the relationship

between HSC cooperation and HSCR but not between HSC adoption and HSCR. The study suggests that AI-enabled systems can help HSC stakeholders effectively manage disruptions by enhancing adaptability and collaboration.

[35] examined the direct and indirect impacts of Artificial Intelligence (AI) on supply chain resilience (SCRes) and supply chain performance (SCP) amid supply chain dynamism and uncertainty. Utilizing Organizational Information Processing Theory (OIPT), the research framework was tested through structural equation modeling (SEM) with survey data from 279 firms across various sectors and countries. Findings indicate that AI enhances SCP in the short term and suggests leveraging AI's information processing capabilities to build SCRes for sustained SCP. This pioneering study provides empirical evidence on optimizing AI for long-term SCP benefits and recommends further longitudinal investigations for deeper insights.

[36] offers a comprehensive review of the literature on Supply Chain Risk Management (SCRM) and its intersection with Artificial Intelligence (AI) techniques. It explores how AI can enhance rapid and adaptive decision-making in SCRM by analyzing large, multidimensional data sources. The study categorizes existing research based on AI methodologies, including mathematical programming, machine learning, and big data analytics, and their application to SCRM tasks such as risk identification, assessment, and response. The review also identifies gaps and unexplored areas in the current literature, proposing future research directions at the convergence of SCRM and AI.

3. GAPS IN LITERATURE

While existing studies have explored AI's role in supply chain mode selection, success factors for AI adoption, and enhancing supply chain resilience, there is limited research focused on how AI can directly manage inventory to minimize waste and enhance resilience in healthcare contexts. This study aims to address this gap by investigating AI-driven inventory management techniques, and their potential to optimize resource utilization, reduce wastage, and strengthen the supply chain's ability to withstand disruptions.

4. METHODOLOGY

In order to ensure a comprehensive investigation, the study adopts survey research design, which allows for collating opinion of the relevant respondents in relation to supply chain management. This method allows for quantifying the responses provided, which was usable for analytics purposes. It is a cross-sectional study that seeks to improve supply chain management in the healthcare sector. The population of the study consists of healthcare administrators, healthcare supply chain consultants, vendors, and suppliers of healthcare products, procurement officers, logistics coordinator, and inventory managers in the United States. The population composition was dictated by the need to gather accurate information from personnel that can provide first-hand information based on their experiences with supply chain management in the healthcare sector.Given the nature of the study, an online questionnaire will be adopted and administered to the aforementioned professionals. To ensure a detailed and representative sample, a stratified sampling method was employed. The decision to adopt this sampling method is to ascertain that opinions are gathered from individuals from different categories. Utilizing different opinions enables the researcher to obtain valuable insights that will contribute to the objectives of the study. Below is the table presenting the expected number of participants per categories.

Table – 1: Sampling Frame

Professionals	Expected Participants
Healthcare Administrators,	136
Healthcare Supply Chain Consultants,	109
Vendors and Suppliers of Healthcare Products	87
Procurement Officers	56
Logistics Coordinator	88
Inventory Managers	122
Total	598

A total of 598 healthcare professionals with substantial knowledge of supply chain and inventory management were the samples for this study. This approach will help with gathering of diverse perspectives on AI-driven inventory management from various stakeholders involved in the supply chain. Additionally, reaching out to professional associations, industry conferences, and online platforms dedicated to healthcare supply chain management can help in identifying and contacting suitable respondents.

4.1 Reliability of the Research Instruments

To ensure the reliability of the research instruments, a pilot test was conducted with a sample of 30 respondents' representative of the target population. The survey questionnaire was evaluated using Cronbach's alpha to assess internal consistency, yielding a value of 0.85, indicating high reliability. Furthermore, test-retest reliability was measured by administering the same survey to the pilot group after two weeks, showing a correlation coefficient of 0.82. These results confirm that the research instrument is reliable and capable of consistently capturing the necessary data on AI-driven inventory management and supply chain resilience in healthcare.

4.2 Data Analysis

Data collected from the survey will be analyzed using machine learning algorithms to derive meaningful insights. Initially, data pre-processing steps will include cleaning, normalization, and handling missing values to ensure data quality. Descriptive statistics will summarize respondent demographics and key variables. Various machine learning techniques, such as decision trees, random forests, will be utilized to identify patterns and relationships between AI-driven inventory management, waste reduction, and supply chain resilience. Model performance will be assessed using metrics such as accuracy, precision, recall, and F1 score. In addition, feature importance analysis will highlight the most influential factors in the study.

For this study, Python was used to apply the machine learning techniques. The data was pre-processed before using a machine learning algorithm for the analysis. Initially, data cleaning was performed by removing duplicates, standardizing formats, and addressing outliers. Missing values were handled using mean imputation for numerical data and mode imputation for categorical data. Columns with excessive missing values were dropped. Categorical variables were encoded using one-hot encoding. Finally, feature scaling was applied using standardization to ensure numerical features were on a similar scale. These steps ensured the dataset's quality and suitability for machine learning analysis.

4.3 Ensemble Methods

Ensemble methods combine multiple machine learning models to improve predictive performance. One widely used ensemble method is the Random Forest algorithm. This method involves generating numerous decision trees during training and then determining the output by taking the majority vote for classification tasks or averaging the predictions for regression tasks from all the individual trees. The equation for the Random Forest classifier can be written as:

$$y(x) = mode\{T(x, \Theta k)\}_{k=1}^{K}$$

Where,

y(x) is the predicted class for input x.
T(x,Θ) is the predictor of the k-th tree in the forest.
K is the total number of trees in the forest.

4.4 Ethical Considerations

This study adheres to strict ethical guidelines to ensure the integrity and confidentiality of the research process. Informed consent was obtained from all survey participants, who were informed about the study's purpose, procedures, and their right to withdraw at any time without penalty. Data privacy and confidentiality were upheld by anonymizing participant responses and securely storing the data. The study received approval from the appropriate institutional review board (IRB), ensuring adherence to ethical guidelines. Additionally, potential conflicts of interest were disclosed, and all findings will be reported honestly and transparently, avoiding any form of data manipulation or bias.

5. RESULTS

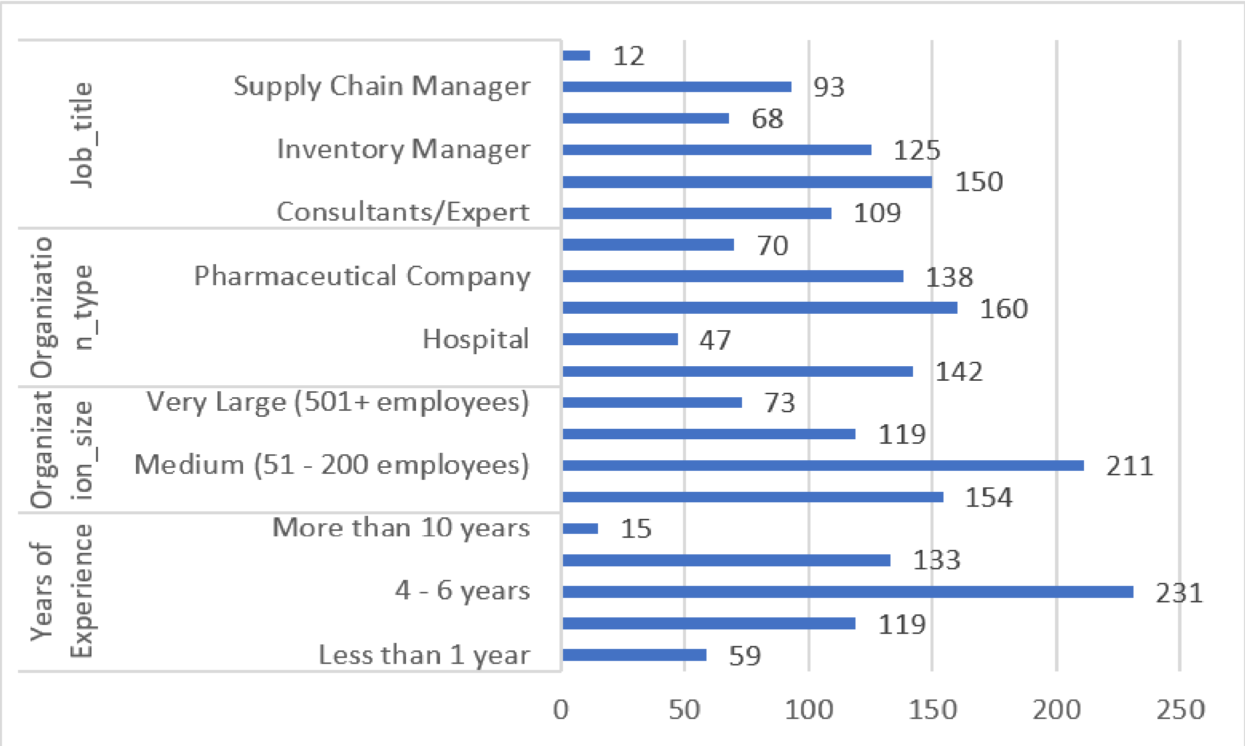

Figure – 1: Descriptive Analysis of Socio-Demographic Characteristics of Participants

The socio-demographic characteristics of the respondents, as depicted in the chart, reveal a diverse and comprehensive sample from the healthcare sector. The majority of respondents have 4-6 years of experience (231), indicating a significant proportion of mid-career professionals, followed by those with 7-10 years (133) and 1-3 years (119) of experience. Regarding organization size, most participants come from medium-sized organizations (211), with notable representation from small organizations (154), large organizations (119), and very large organizations (73). The types of organizations vary widely, with medical device manufacturers (160) and clinics (142) being the most represented, followed closely by pharmaceutical companies (138). The job titles of respondents further reflect this diversity, with healthcare administrators (150) and inventory managers (125) forming the largest groups, while consultants/experts (109) and supply chain managers (93) also have significant representation. This wide range of experience levels, organization sizes, types, and job roles suggest a well-rounded and comprehensive sample, providing robust insights into the healthcare sector's inventory management practices.

Table – 2: Current Inventory Management Practices

Questions	Frequency	Percentage
How do you currently manage inventory in your organization?		
Manual	12	2.2
Advanced inventory management software	164	29.4
AI-Driven inventory management systems	48	8.6
Basic inventory management software	243	43.6
Spreadsheet-based systems	90	16.2
How effective do you find your current inventory management practices in reducing waste?		
Effective	252	45.2
Moderately Effective	196	35.2
Slightly Effective	12	2.2
Very Effective	97	17.4
How often do you experience stockouts or overstock situations?		
Frequently	263	47.2
Occasionally	60	10.8
Rarely	99	17.8
Very Frequently	90	16.2
Very Rarely	45	8.1

Table 2 reveals insights into current inventory management practices across organizations. Manual inventory management is utilized by a small fraction of respondents (12), while advanced inventory management software is used by a significant number (164), indicating a preference for sophisticated systems. AI-driven inventory management systems are less common (48), but still present. Basic inventory management software is the most widely used (243), followed by spreadsheet-based systems (90). When evaluating the effectiveness of these practices in reducing waste, 252 respondents find them effective, while 196 find them moderately effective. A smaller number (97) consider them very effective, and very few (12) find them slightly effective. Stockouts or overstock situations are frequently experienced by 263 respondents, with 90 experiencing them very frequently. Conversely, 99 experience these situations rarely, and 45 very rarely, showing a variance in inventory management success.

Table 3: AI Adoption in Inventory Management in Healthcare Industry

Questions	Frequency	Percentage
To what extent has your organization adopted AI-driven solutions for inventory management?		
Extensively Adopted	59	10.6
Fairly Adopted	219	39.3
Fully Adopted	30	5.4
Moderately Adopted	111	19.9
Not Adopted	138	24.8
What types of AI technologies are used in your inventory management system?		
Computer vision	50	9.0
Machine learning algorithms	121	21.7
Natural language processing	61	11.0
Predictive Analytics	136	24.4
Robotics process automation	50	9.0
How would you rate the ease of integrating AI solutions into your existing inventory management system?		
Difficult	224	40.2
Easy	64	11.5
Moderate	148	26.6
Very difficult	93	16.7
Very easy	28	5.0

Table 3 highlights the adoption of AI-driven solutions in inventory management within the healthcare industry. Adoption levels vary, with 59 organizations extensively adopting AI, 219 fairly adopting it, and only 30 fully adopting AI-driven solutions. Moderate adoption is reported by 111 organizations, while 138 have not adopted AI at all. Various AI technologies are employed, with predictive analytics being the most prevalent (136), followed by machine learning algorithms (121). Natural language processing is used by 61 organizations, while both computer vision and robotic process automation are each utilized by 50 organizations. When it comes to integrating AI solutions, a significant number of respondents (224) find the process difficult, while 93 find it very difficult. Conversely, 148 rate the integration as moderate, and fewer respondents find it easy (64) or very easy (28). This illustrates the varying degrees of AI adoption, and the challenges faced in integrating these technologies into existing systems.

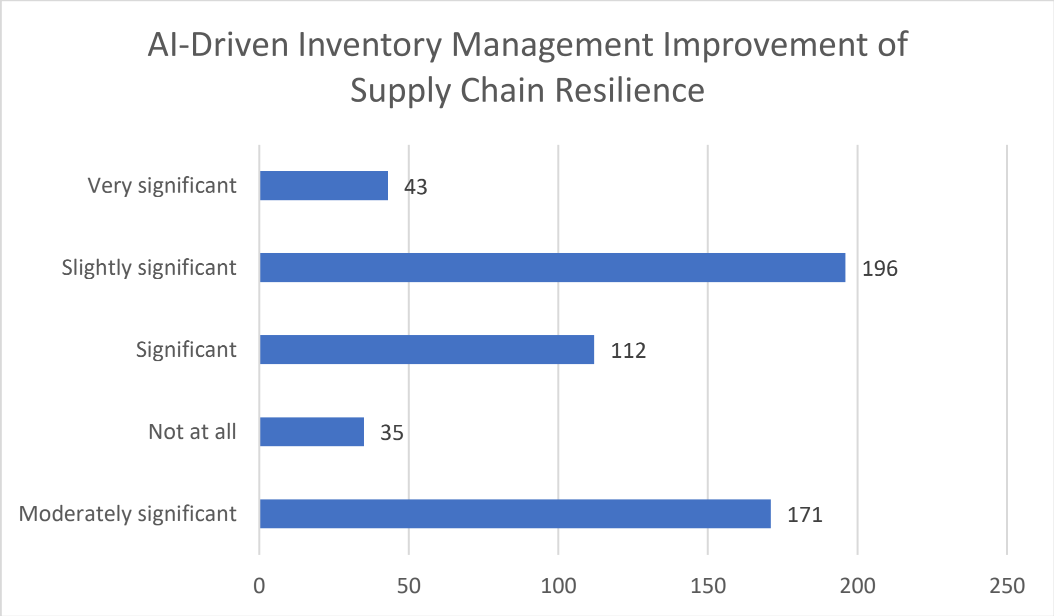

Figure – 2: AI-Driven Inventory Management Improving Supply Chain Resilience

As reported in the figure above, 196 of the respondents were of the opinion that there is a slight improvement of supply chain resilience, followed by 171 of them that said there is moderate improvement, 112 of them believe there is significant improvement, while 43 of them were of the opinion that the improvement is very significant. However, about 35 of them think AI-Driven inventory management does not have impact on supply chain resilience.

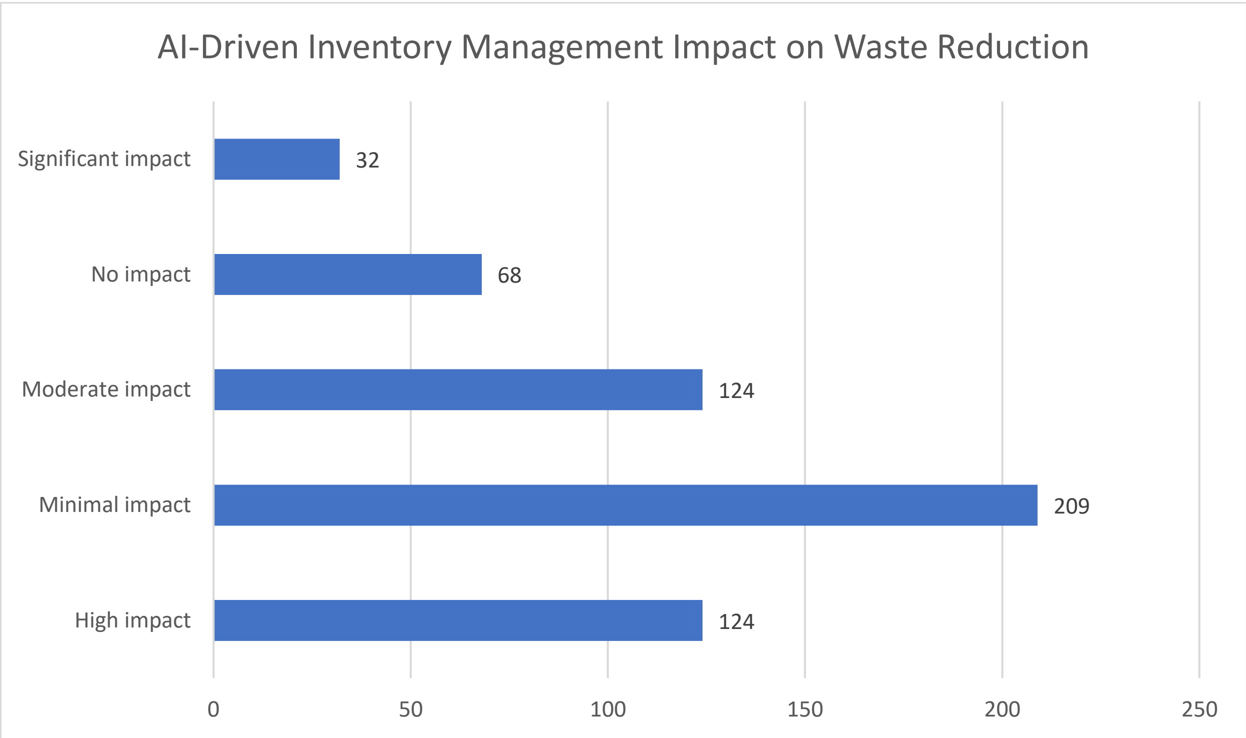

Figure – 3: AI-Driven Inventory Management Impact on Waste Reduction

As reported in Figure 3, it could be seen that 209 of the participants were of the opinion that AI-Driven inventory management has minimal impact on waste reduction, on the other hand, 124 of them believed that it has high impact with another 124 respondents with the perception that the impact is moderate. 68 of the respondents indicates that AI-Driven inventory management does not have impact on waste reduction.

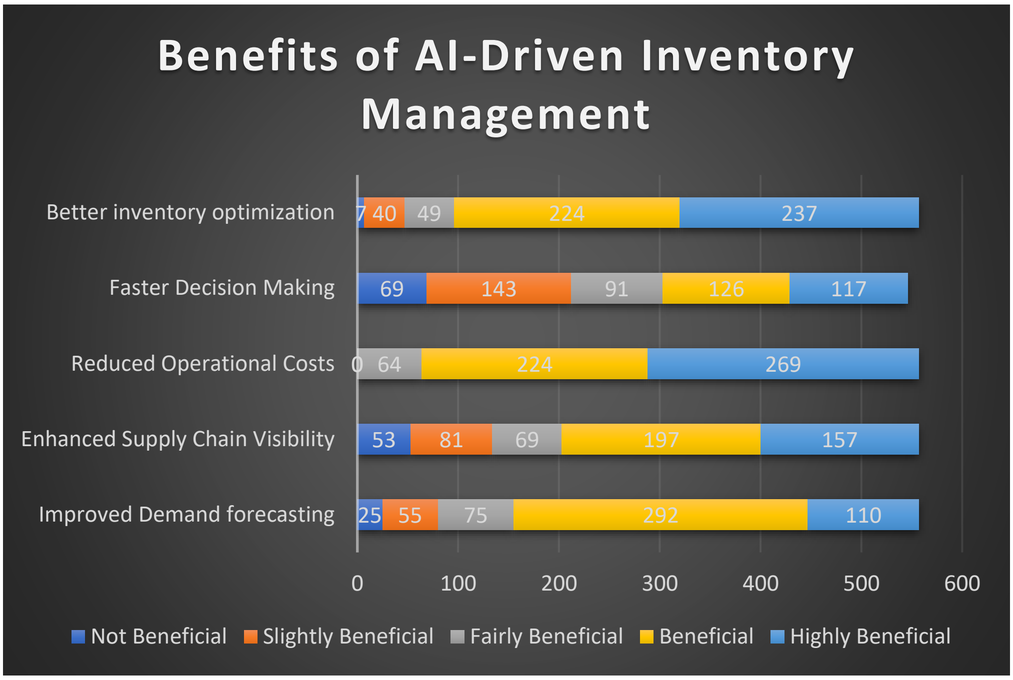

Figure – 4: Benefits of AI-Driven Inventory Management

The data on the benefits of AI-driven inventory management highlights several key advantages, with improved demand forecasting being seen as beneficial or highly beneficial by a majority of respondents (292 and 110, respectively). Enhanced supply chain visibility also received strong positive feedback, with 197 finding it beneficial and 157 highly beneficial, underscoring its importance in improving coordination and reducing inefficiencies. The reduction of operational costs stands out as particularly compelling, with no respondents finding it not beneficial, and the majority (269 and 224) rating it as beneficial or highly beneficial. Faster decision-making showed more varied responses, though still positive overall, with 126 finding it beneficial and 117 highly beneficial. Lastly, better inventory optimization was highly regarded, with 224 respondents finding it beneficial and 237 rating it as highly beneficial, reflecting AI's effectiveness in maintaining optimal inventory levels and preventing both overstock and stockouts.

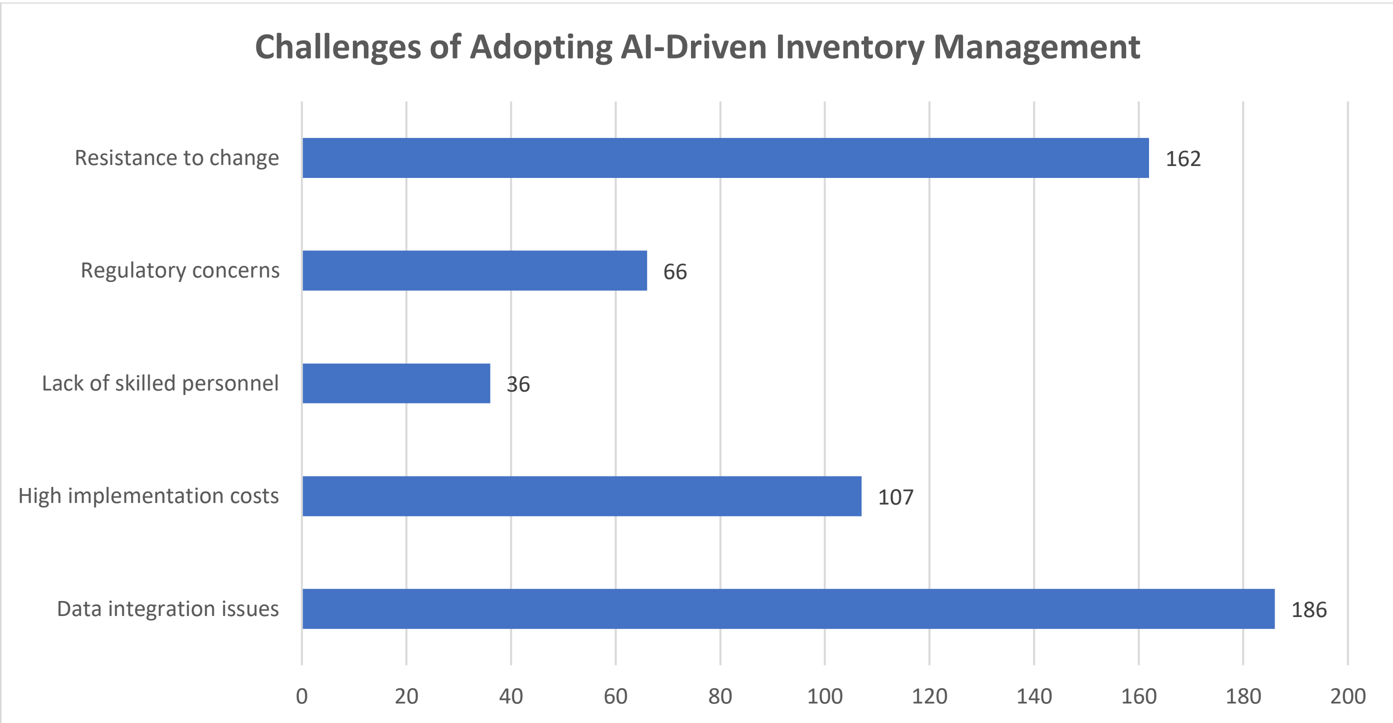

Figure – 5: Challenges of adopting AI-Driven Inventory Management

The main challenges faced in adopting AI-driven inventory management are diverse, reflecting the complexities associated with integrating advanced technologies in the healthcare. The most frequently cited challenge is data integration issues, with 186 respondents indicating difficulties in merging AI systems with existing data frameworks. Resistance to change is another significant barrier noted by 162 respondents, highlighting organizational reluctance toward adopting new technologies. High implementation costs are also a concern for many, with 107 respondents identifying financial constraints as a major hurdle. Regulatory concerns, affecting 66 respondents, indicate the impact of compliance and legal issues on AI adoption. Lastly, the lack of skilled personnel, mentioned by 36 respondents, underscores the need for expertise in managing and implementing AI-driven systems effectively.

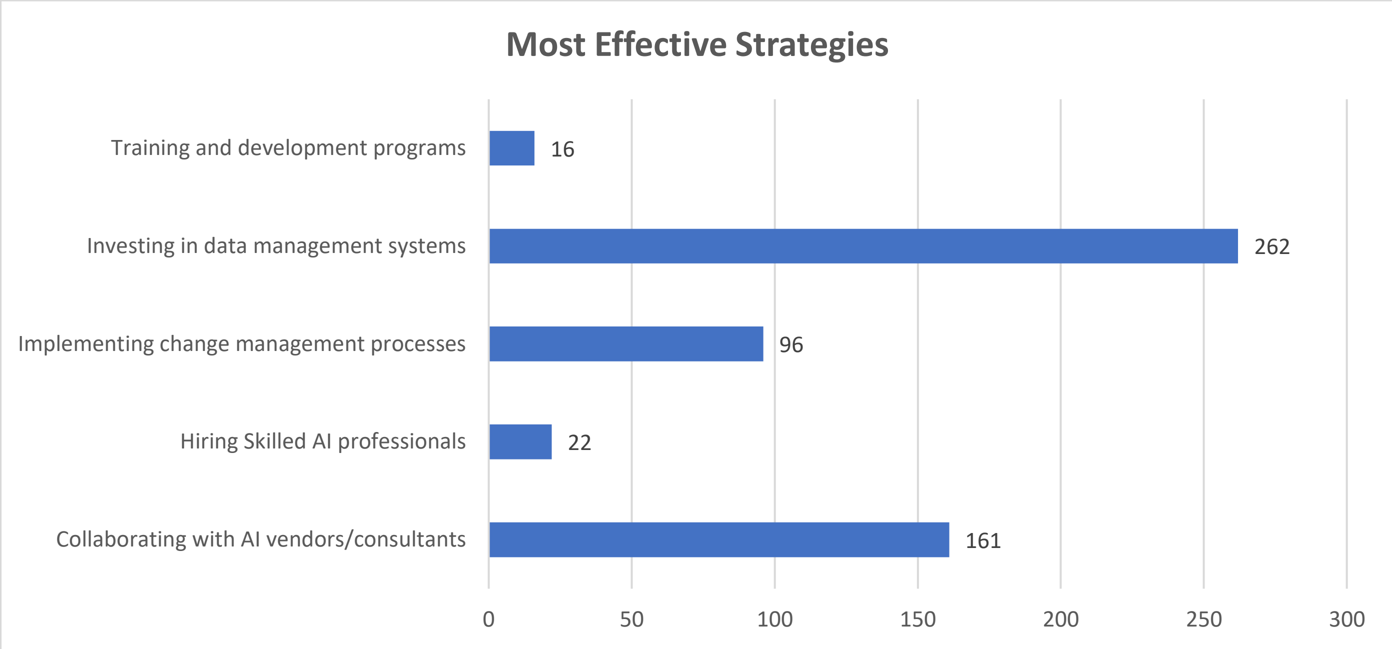

Figure – 6: Most Effective Strategies in Overcoming the Challenges

To overcome the challenges associated with adopting AI-driven inventory management, respondents believe several strategies to be most effective. The most frequently recommended strategy is investing in data management systems, with 262 respondents emphasizing the importance of robust data infrastructure to support AI integration. Collaborating with AI vendors and consultants is also seen as a crucial approach, cited by 161 respondents, suggesting that external expertise can significantly aid in navigating the complexities of AI implementation. Implementing change management processes is another key strategy, with 96 respondents advocating for structured approaches to facilitate organizational adaptation and reduce resistance. Although less frequently mentioned, hiring skilled AI professionals (22 respondents) and developing training programs (16 respondents) are also considered important for building internal capabilities and ensuring successful AI adoption.

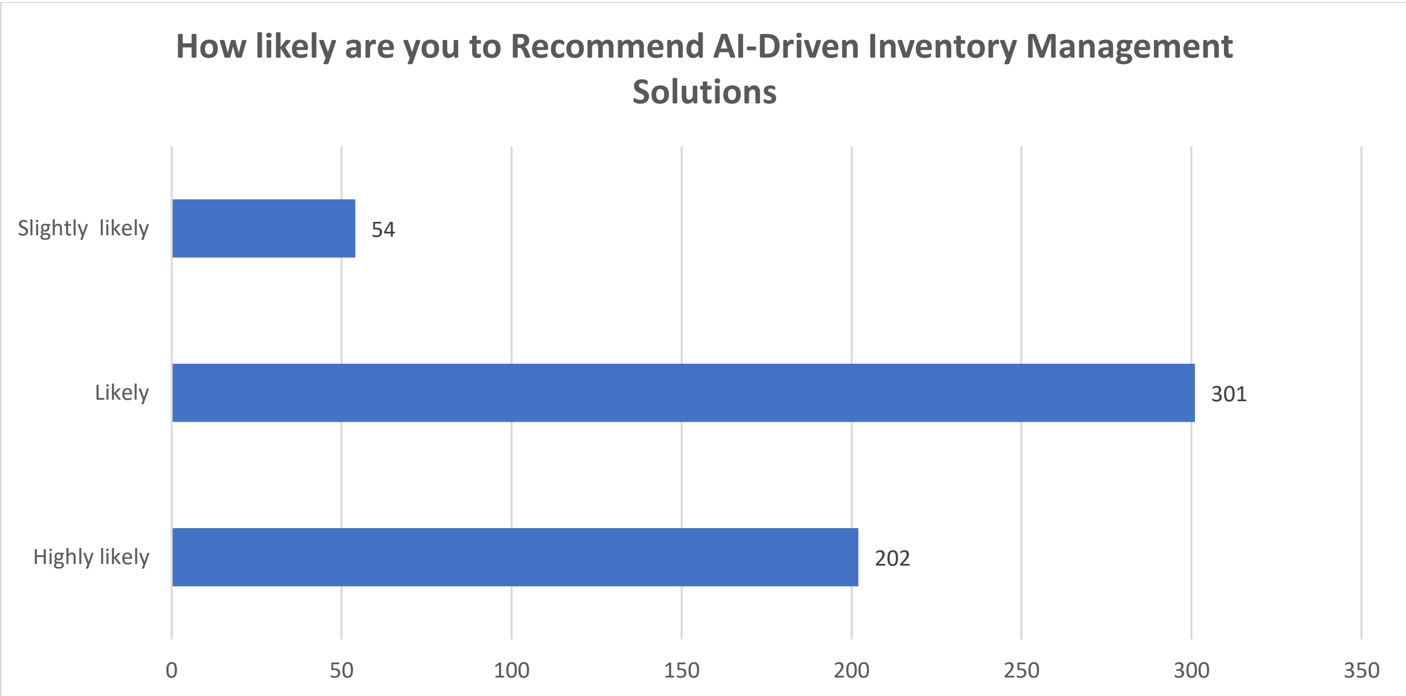

Figure – 7: How likely are you to recommend AI-Driven Inventory Management Solutions

As reported in Figure 7, the likelihood of recommending AI-driven inventory management solutions to other healthcare organizations appears to be high. Out of 557 respondents, 202 indicated they are "highly likely" to recommend such solutions, while 301 respondents said they are "likely" to recommend them. This shows a strong overall endorsement, with only 54 respondents being "slightly likely" to recommend AI-driven inventory management. The data suggests that the majority of respondents view AI-driven inventory management solutions favourably and see their value in enhancing healthcare operations.

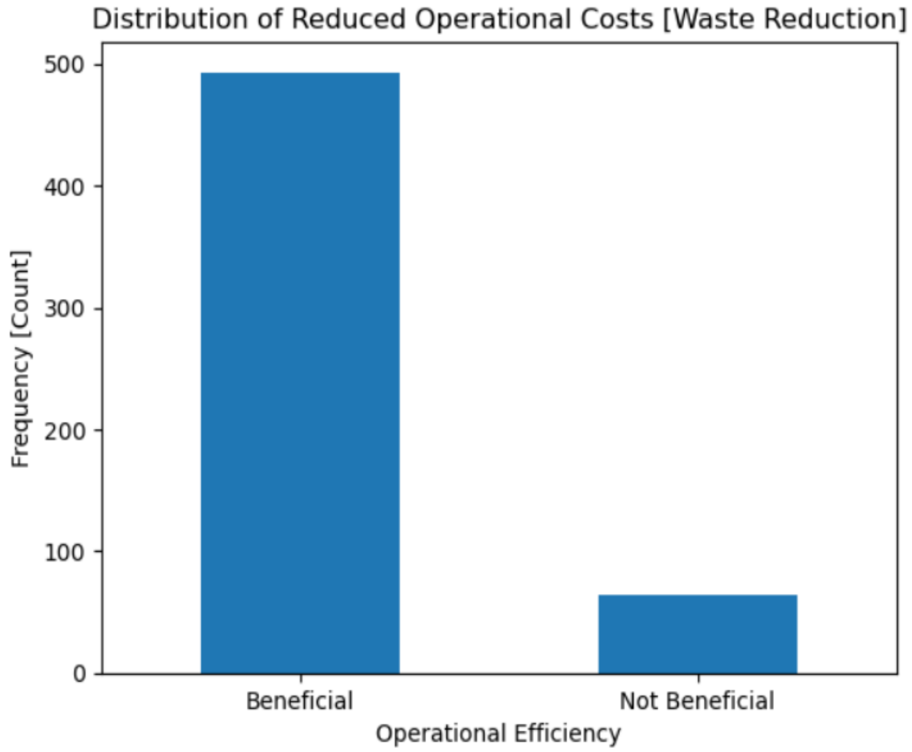

Figure – 8: Distribution of Perception of Respondents on Waste Reduction through AI-Inventory

The perception of the respondents with regards to the benefits of AI-driven inventory as presented in Figure 8, showed that substantial number of them (88%) perceived it to be beneficial, while 12% were of the opinion that it was not beneficial.

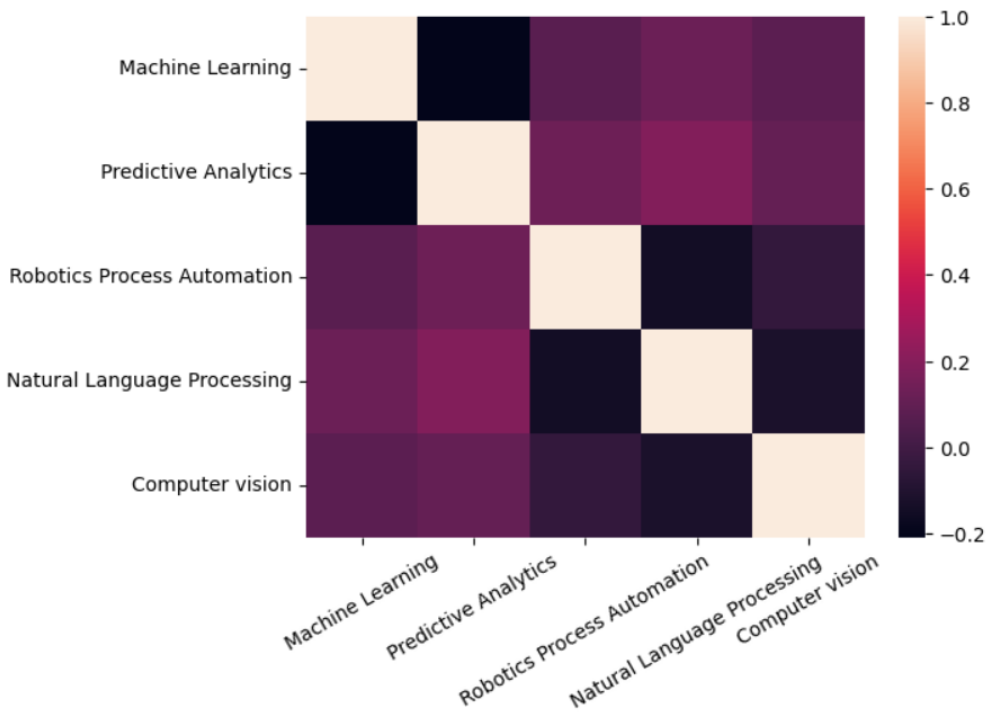

Figure – 9: Heatmap Showing the explanatory variables relationships.

The heatmap showed the correlation analysis, indicating the relationship between a pair of variables. It was revealed that the relationship between all pairs is low, indicating that the relationships are weak, eradicating the possibility of a multicollinearity problem. Hence, the AI-Driven inventory management indicators can be employed for the model.

5.1 Machine Learning Analysis

The metrics employed to test the performance of the models and their respective scores are presented below in Table 4. The study evaluated the models using the F1 score, recall values, accuracy, and precision. Accuracy is defined as the proportion of correctly predicted model variables relative to the entire dataset. This statistic alone is insufficient to evaluate the model comprehensively. Thus, it is essential to consider the F1 score, accuracy, and recall metrics together. Table 4 displays the results of the models that were utilized.

Table 4: Evaluation Metrics for the Random Forest Model

Evaluation Metrics	Random Forest
Accuracy	0.839
Precision	0.782
Recall	0.839
F1 Score	0.809

The Random Forest shows an accuracy score of 83.9%, a precision score 78.2%, indicating that the true positives predicted in the models is 78.2%. The models also demonstrated a recall score of 83.9%, indicating that the actual positive cases correctly identified by the random forest is 83.9%. Lastly, the F1-scores in the random forest is 80.9%.

5.1.1. The Confusion Matrix

The confusion matrix in figure 10 presents the random forest model's performance based on how the target (beneficial and not beneficial) is classified. There are two categories predicted in the confusion matrix, which include beneficial and not beneficial, relating to the ability of the ensemble model to predict waste reduction in the healthcare industry leading to resilience of supply chain. The matrix displays the category distribution based on the prediction between the true label and the predicted label.

It was revealed that 141 instances of "Beneficial" class were correctly classified, while 19 instances of the "Not Beneficial" were incorrectly classified as "Beneficial". Furthermore, 8 instances were incorrectly classified as "Not Beneficial", while no instances of the "Not Beneficial" class were correctly classified.

The evaluation of the model revealed that the model performed well as significant cases of "Beneficial" effect of AI-driven inventory management was correctly predicted. The F1-score of 80.9% indicated an overall excellent performance of the model.

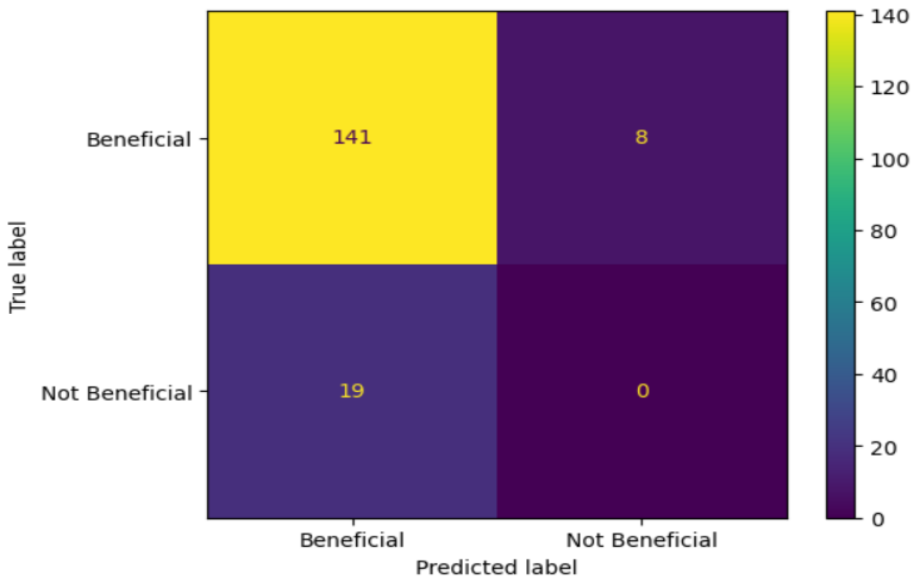

Figure – 10: Confusion Matrix

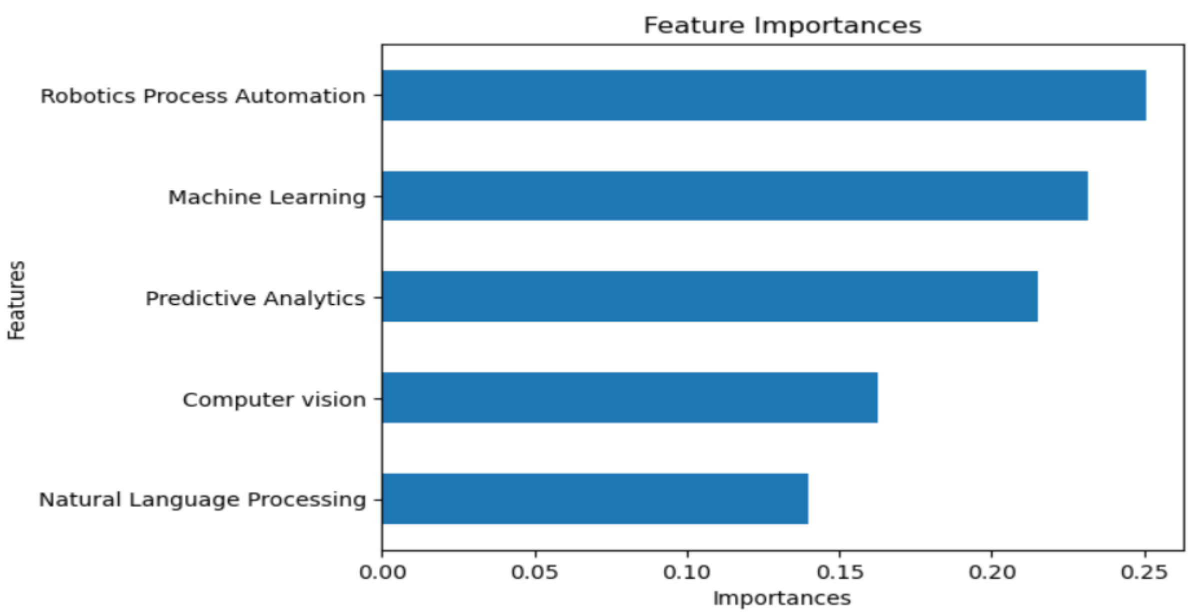

Figure – 11: Feature Importance

Based on the importance of the features as extracted from the random forest model, it could be seen that robotics process automation is the most important feature among the AI techniques applied to inventory management in the healthcare industry. This was followed by the machine learning algorithm, and predictive analytics.

6. DISCUSSION AND CONCLUSION

The findings of this investigation provide insights into the role played by AI-Driven inventory management on supply chain resilience in healthcare, contributing to waste reduction in the process. It was obtained from the results that a significant number of organizations implementing these technologies to various extents. Many organizations have fairly adopted AI solutions, while some have not adopted them at all, indicating an ongoing transition towards AI integration. This is similar to the perspective of [7]. Those that have extensively or fully adopted AI-driven inventory management are reaping considerable benefits in terms of improved demand forecasting, enhanced supply chain visibility, and reduced operational costs. Better inventory optimization is another major advantage reported by [33], highlighting AI's potential to streamline operations and reduce inefficiencies.

Despite the clear benefits, integrating AI solutions into existing inventory management systems presents substantial challenges. A significant portion of respondents finds the integration process difficult, emphasizing the need for better strategies and resources to facilitate this transition. However, a smaller yet notable segment of users finds the integration process manageable, suggesting that with adequate preparation and support, the difficulties can be mitigated. Adopting AI-driven inventory management faces several key challenges, with data integration issues and high implementation costs being the most prominent. Resistance to change within organizations and regulatory concerns also pose significant barriers. To overcome these challenges, investing in robust data management systems and collaborating with AI vendors and consultants are identified as the most effective strategies.

The overall outlook on AI-driven inventory management remains positive. A majority of respondents are likely to recommend AI solutions to other healthcare organizations, indicating a broad recognition of the potential benefits. This positive sentiment underscores the importance of addressing the integration and adoption challenges to fully leverage AI's capabilities in inventory management.

The insights from the machine learning algorithm applied to the data revealed that robotics process automation and machine learning analysis are two most important AI techniques that reduce wastage of resources and enhance supply chain resilience in the healthcare industry. This finding is similar to the empirical evidence reported by [15] revealing that machine learning has been significantly helpful to increase the efficiency of supply chain.

7. RECOMMENDATIONS

7.1 Investment in Data Management Systems: Healthcare organizations should prioritize investment in robust data management systems to facilitate smoother integration of AI solutions.

7.2 Collaborations and Partnerships: Establishing collaborations with AI vendors and consultants can provide the necessary expertise and support for successful implementation.

7.3 Change Management: Implementing effective change management processes can help mitigate resistance and ensure a smoother transition to AI-driven systems.

7.4 Training and Development: Developing comprehensive training and development programs for existing staff can address the skill’s gap and enhance the effectiveness of AI adoption.

7.5 Pilot Programs: Organizations should consider starting with pilot programs to test AI-driven inventory management solutions on a smaller scale before full-scale implementation, allowing for adjustments based on initial outcomes.

8. AREAS FOR FUTURE RESEARCH

Future research could explore the integration of advanced AI-driven techniques like deep learning and reinforcement learning to further enhance inventory management in healthcare supply chains. Additionally, examining the impact of real-time data analytics and IoT on supply chain resilience and waste reduction would be valuable. Investigating the ethical and privacy implications of AI applications in healthcare supply chains, as well as conducting longitudinal studies to assess long-term benefits and challenges, are also important areas for future research.

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