

Implementing AI for Dynamic Demand Forecasting in Lean Healthcare Logistics: A Case Study Approach



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Abstract This research aims at establishing the contribution of AI in improving dynamic demand forecasting in lean healthcare logistics. Using a case study approach, the paper explores the effectiveness of adopting the AI-based advanced models such as LSTM in forecasting the demand for health care and distinguishing it from other models such as ARIMA. The results of the work indicate that compared to other methods, application of AI-based models radically improves the accuracy of the forecasts with predetermined variables, while LSTM shows a nuance RMSE value which is 31% less than ARIMA. Also, the study links intended AI-based forecasting to lean concepts, as well as the elimination of current waste and timely replenishment of stock based on real-time demand changes. However, this study also reveals barriers concerning data quality, the issues of recalibration, and the issue of integrating such systems with the traditional models of working healthcare logistics systems. H2 is that this paper elucidates the practical solutions for using AI in the healthcare logistics and provides the healthcare organizations with the strategic directions of AI application in demand forecasting for sustainable improvement in the organization's performance. Thus, the results have outlined the applicability of AI in enhancing the logistics of the healthcare sector, but at the same time have highlighted the continuous process of change and development to meet the changes in the healthcare sector.

Keywords Artificial intelligence (AI) · Dynamic demand forecasting · Lean healthcare logistics · Series analysis · Healthcare resource allocation · Inventory management supply chain management

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1 Revolutionizing Forecasting in Health Care

Dynamic demand forecasting plays an important role in improving the effectiveness of healthcare to respond to dynamic supply chain. In this case, accurate forecasting helps the healthcare systems to adjust their practices to the changes in the demand and to have the necessary stock of medical resources. Accurate demand forecasting helps in effective allocation of resources and thus little or no wastage of healthcare stocks [1]. The healthcare needs vary in the market owing to factors such as flu seasons and epidemics. The time series forecasting models including LSTM are found to yield better results compared to others since they consider these variations making supply chain more responsive [2, 3]. More complex models such as deep learning have exhibited even higher accuracy in estimating patient demand and logistics requirements, and therefore help in efficient management of healthcare resources [4]. Innovative techniques that are capable of capturing long run data movements and reduce the influence of historical data make the forecasts more realistic, which is very important in dealing with the intricacies of healthcare chain [5]. Although the dynamic demand forecasting improves healthcare logistics considerably, there are issues such as data quality and the model needs to be recalculated frequently because of frequent variations in demand patterns. To maintain proficient healthcare delivery systems, the following issues must be addressed. AI is disrupting the conventional modes of demand forecasting in Lean healthcare logistics, in terms of precision and speed. The use of more sophisticated algorithms, especially that of a deep learning nature such as LSTM, enables the generation of more accurate forecasts that are beneficial in the effective handling of supplies. LSTM models are superior to ARIMA-based methods in predicting the medicine demand, with an RMSE of approximately 2.0 while on the same variable, ARIMA model had 9.35 [2]. Of the various methods, a deep learning approach seemed to produce an average absolute percentage of roughly 4%, suggesting improvement on the prevalent problems of forecasting volatility [6]. Therefore, it leverages on the applications of AI technologies such as machine learning and natural language processing to analyze large volumes of datasets with a view of making timely adjustments to inventories [7]. SARIMA has been seen as an incredible tool in time series analysis that captures long-term dependencies within inventory volatility thus improving demand forecasts [8]. The implementation of AI forecasting is also in line with Lean in terms of reduction on rates of wastage and maintaining optimum levels of inventory so that healthcare service providers prepare for patients' requirements promptly [9]. As has been found, AI has the capability to bring about a radical shift in how things are run and this has been witnessed in the case of healthcare logistics; however, some significant issues that must be overcome in order to ensure that AI adoption is successful include: The quality of data that is to be used in making decisions The integration of the AI system adopted with the existing systems that are already in place.

Therefore, the paper's objective is to examine how the incorporation of AI tools can be integrated into healthcare logistics to reduce the variability of demand forecasts. Using a case study approach, this study aims to offer useful findings on the

advantages and disadvantage of AI in the real-life organization. The major challenge addressed by the study in terms of the application of artificial intelligence is the enhancement of the detail of the demand forecasts, which will also help to enhance the inventory control and, thus, avoid waste [10]. It explores the challenges encountered in the usage of AI including issues to do with data privacy and high implementation costs [10, 11]. The study does propose an action plan for the application of AI in the healthcare facilities' supply chain management while stressing the green initiative [11]. As the case study shows, it is possible to get a broader understanding and the considerations that are needed to implement AI [12]. It enables the integration of the views and insights of various stakeholders in the health profession hence increasing the applicability of the outcomes [12]. The method used is effective for identifying necessary lessons learned should similar endeavors for applying AI in the healthcare logistics context be attempted in the future [12]. Hence, while the case study approach yields quite deep insights; it still remains one of the most potent ways of comprehending the complex processes involving AI in health logistics.

2 AI-Powered Precision in Logistics

AI technologies increase the accuracy in demand of forecasts the Lean healthcare logistics due to the use of better algorithms as well as utilization of data analysis compared to conventional methods as visually represented in Fig. 1. The use of AI integrated means that there is better prediction and therefore better stock management, a better system as a whole. AI models especially LSTM networks are also seen to perform better than the traditional method of demand forecasting with Automated Reconstructive Integrated Moving Average (ARIMA) as depicted in Fig. 1. For example, in LSTM the RMSE was equal to 2. ARIMA had an RMSE of 9 and ETS had 0 as an RMSE as shown below: 35 are higher showing a significant enhancement of the accuracy as compared to the previous numbers [2]. Advanced computing with large databases of data is used, and the results show improved and more accurate patterns of demand and application of adjustments of inventory levels as illustrated in Fig. 1 [7]. AI technologies leverage real-time data from sources such as the social media and customer reviews, and feed them into the models to improve demand estimation a technique that traditional methods fail to consider [7]. Fitting AI in the logistics field lets regular restocking and adjusting inventories in real time, and this real-time adjustment process is depicted in Fig. 1, which closes the gaps in stock differentiation [10]. They further hold that AI-driven demand forecasting improves the accuracy of forecasts and at the same time minimizes costs traced to overstocking and stockouts as shown in Fig. 1, thus improving the efficiency of distribution of health resources [13]. The application of deep learning provides insights into complex relationships within and across supply chain data relevant to the improvement of the decision-making and supply chain performance [14]. Advanced predictive models of AI produce a substantial improvement in the

forecast models of healthcare logistics than ordinary logistic models this improvement is clearly presented in Table 1 LSTM models yield a better. These models employ complex algorithms that help with examining highly complex data making the demand forecasting more dynamism and accurate. Comparing with traditional model like ARIMA, research found newer model such as long short-term memory (LSTM) yield better performance in terms of error rate of 2.0 as opposed to 9.35, and R-squared value of 0.952 as opposed to 0.24 [2]. The CCLR-DL framework incorporates statistical techniques with deep learning and leads to the enhancement in the accuracy of forecasts along with interpretability [15]. Real-time data processing: AI models can go through real-time data such as actuality and analyze unstructured data available in social media platforms in order to tweak the forecast actively to make the model highly sensitive to changing market conditions [7]. By utilizing AI in inventory, firms are capable of making prior adjustments to avoid running out of stock and at the same time avoid overstocking [16]. However, such improvements are still obstacles in areas of interpretability and in handling of data in general, which may prevent the easy application of AI-based models in healthcare logistics. Due to such advantages that state that they offer efficiency and get an accurate output, they are considered ideal for supply chain management today.

2.1 AI Versus Traditional Methods

AI also increases the level of accuracy in demand forecast in relation to the Lean healthcare logistics compared to conventional techniques by use of enhanced algorithms and machine learning. These shifts result in increased precision in forecasting demand for healthcare supplies as well as increased versatility in terms of time required to provide such forecast as suggested below. Some form like long short-term memory (LSTM) surpasses other conventional methodologies of time series forecasting including ARIMA. For instance, in LSTM, the RMSE was 2.0 which was way better than ARIMA's projection of 9.35 which proved to have a significantly improved predictive accuracy than the models with values less than 35 [2]. It eliminates the inefficiencies that traditional models have of missing out on these complexities while making their predictions [17]. AI systems can work in real-time data which are available in social media and customer feedback to improve the demand forecasting as they consider up-to-date market trends as summarized in Table 1 [7]. Machine learning techniques enable mechanized revisions to product stock levels leveraging on analytics forecasts so as to react promptly to changes in demand [6]. This is because applications of Artificial Intelligence enhance healthcare resource management and patient appointments leading to decreased waiting time and operational expenses by as much as 81%. Therefore, it is 23% more effective than the traditional methods [13]. Some advantages of AI-driven models are real-time data analysis, changeability, and accuracy in prediction and this applies to various fields these advantages are also highlighted in Table 1. These models take advantage

AI-Driven Dynamic Demand Forecasting in Lean Healthcare Logistics

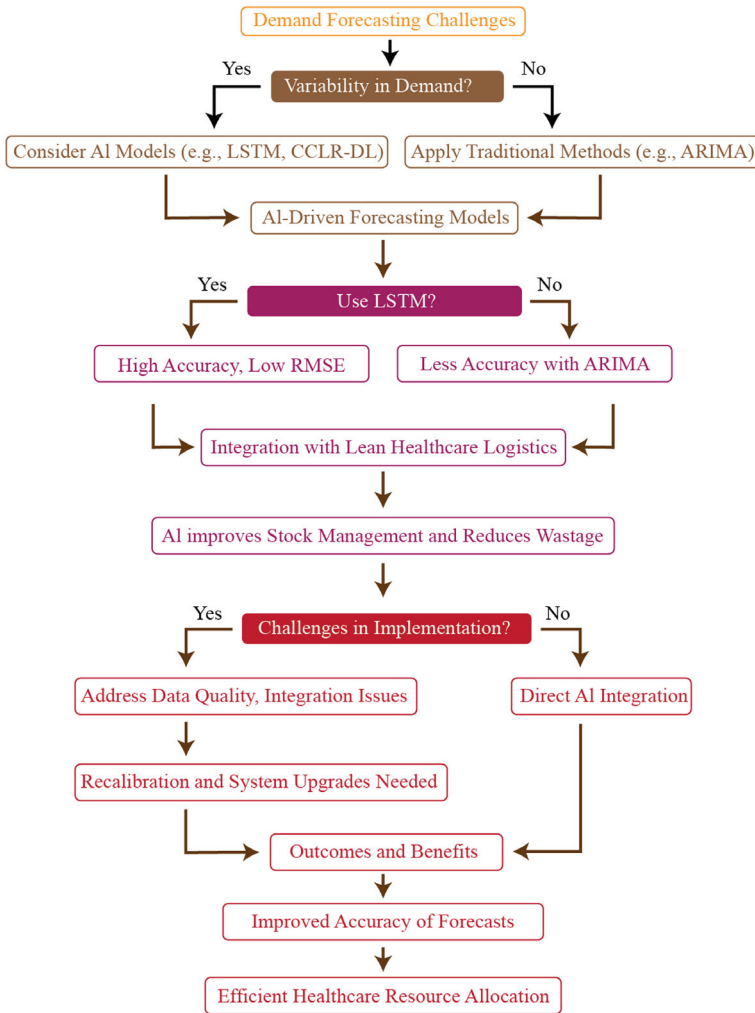


Fig. 1 AI-driven dynamic demand forecasting process in lean healthcare logistics

of vast numerical algorithms to support the improving of decision-making and operation. Hypothesis One: Technology advancement specifically in AI system allows for the quick identification of large chunks of data and immediate decision-making. For instance, AI for analytics can innovate data platforms into adaptive environments for organizations to act quickly on existing conditions [18]. In industries today, the use of cloud-based machine learning for the prediction of equipment failures based on real-time data taken, improves operational reliability for industrial equipment which used for maintaining machines [19]. AI models are flexible since the model

Table 1 Key advantages of AI models over traditional methods in healthcare demand forecasting

Criteria	AI-based models (e.g., LSTM, CCLR-DL)	Traditional methods (e.g., ARIMA, ETS)
Accuracy (RMSE value)	Significantly lower RMSE (e.g., LSTM: 2.0, CCLR-DL: improved accuracy with deep learning)	Higher RMSE (e.g., ARIMA: 9.35, ETS: less accurate for complex patterns)
Data handling	Capable of processing large volumes of real-time, unstructured data	Limited to historical, structured data
Adaptability	Highly adaptable to new data and changing conditions	Less adaptable, often requires manual recalibration
Seasonal variations	Effectively captures long-term and seasonal dependencies (e.g., SARIMA integration)	Limited capability in capturing seasonal variations
Predictive power	High predictive accuracy for dynamic, nonlinear trends	Moderate predictive power, better suited for linear trends
Real-time processing	Supports real-time data processing and dynamic adjustments	Typically relies on static historical data
Implementation complexity	More complex to implement, requires high computational resources	Easier to implement, but may not handle complex scenarios effectively
Interpretability	Enhanced interpretability with hybrid models (e.g., CCLR-DL)	Generally straightforward but less powerful in handling complex data patterns
Impact on inventory management	Reduces stockouts and overstocking through precise forecasting	Prone to errors leading to inefficient inventory management
Integration with Lean principles	Strong alignment with Lean principles, reduces waste, and optimizes resource allocation	Less efficient in aligning with Lean principles, may result in higher wastage

can learn from new inputs introduced into the system. This flexibility is especially valuable in highly volatile spheres, for instance, drug discovery, where AI optimizes the process of creating treatments by responding to new data in the biomedical field [20, 21]. Through use of machine learning technology in advertisements, this makes the process of advertising flexible and adaptable by frequently analyzing its effectiveness and impact on the performance of the business [21]. AI machine learning ways of predicting outcomes also show higher accuracy than other more traditional ways. For instance, utilizing deep learning models paved way to improving the accuracy of COVID-19 management and response plans that correspondingly, results to quicker identification and management. There must be proper utilization of random forest algorithms in the predictive maintenance that has been found useful in developing accurate predictions of the wear level of any equipment, thus proving the versatility of AI applications [19].

2.2 Technological Tools

There is a shift in makeup of the dynamic demand forecasting within the healthcare logistics that focused on the technologies like machine learning and predictive analytics. They therefore improve the likelihood of assessing healthcare demands affording increased efficiency in supply chain. LSTM models also give fewer errors in medicine demand prediction compared to traditional ARIMA models, more accurate (RMSE of 2.0 as compared to 9.35) [2]. The CCLR-DL approach combines statistical methods with the deep learning approach and as a result increases the accuracy of forecasting while ensuring increased interpretability as evidenced by the clinical visits in Catalonia [15]. Advanced statistics such as use of deep learning feature that permits automatic learning of features and handling of complicated patterns easing the forecasts in the health care [17]. There are some recent advancements that have proven the ability of deep learning models in the context of predicting the patient's travel needs across borders in dynamic environments [4]. Foreign models such as the machine learning and deep learning, LSTM, and CCLR-DL hybrid framework are now being deployed in the healthcare logistics system to improve demand forecast. These technologies make use of past data to drive the appropriate supply chain processes making it easier to obtain medical supplies on time. The current analysis found out that the LSTM models yield a better forecast of the medicine demand compared to the traditional ARIMA, based on their RMSE (2.043 and 8.926, respectively) as well as the R^2 value (0.912 and 0.16 respectively) as the RMSE values are compared in Table 1 [2]. LSTM has the advantage of obtaining heavy burden patterns at time sequence information and is much better for healthcare logistics for its complex demand impact. The CCLR-DL formed statistical methods with LSTM, which increases the forecasting accuracy while still able to select features in order to provide explainability [15]. The level of accomplishment has been worked out to a significant performance, whereby managers can be better prepared for changes in demand for healthcare [15, 22]. A novel approach is the MCDFN model which combines CNN, LSTM, and GRU, thus improving the predictive accuracy because it includes spatial and temporal data [22]. The model has had comparatively better results than other deep learning models to highlight the need for explainability in demand forecasting [22]. On the other hand, while LSTM and hybrid models demonstrate good performance, these are complex and can present problems with interpretability and affinity with legacy systems which thus requires further work in obtaining improved models with reasonable complexity.

3 Dynamic Demand Forecasting: The AI Advantage

Indeed, it dramatically contrasts with static, nonchanging models of the demand forecasting. Dynamic is characterized by the inclusion of real-time data that helps react to several conditions, which makes it suitable for use in the healthcare industry.

This flexibility is unique since the intensity and nature of patients' needs as well as disease incidences varies in distinct restrained moods. There are two types of models available in the market: dynamic models, which use real data to keep adjusting the forecast as per the current situation, and static models, which use past averages and do not take into considerations the sudden changes in demand as implemented in LSTM as opposed to ARIMA [2]. This ostensibly disregards state variables and ever evolving consumer preferences thereby developing biased demand elasticity estimates in static models. The biases mentioned above do not affect dynamic models as such models involve several variables as well as continuously adapt to new data [23]. Also, the application of dynamic forecasting is appropriate for demand management of the healthcare product in acting contingently to unsteady disease trends as demonstrated in COVID-19 cases [3, 24]. Such enhanced models such as CCLR-DL, integrate statistical procedures with deep learning to improve the forecast of healthcare demands where the demand is complex [15]. These advantages come with several strings attached, which are the need for reliable data and analytical capacity, which is not easy for some organizations. However, they are strength suited to delivering real-time information as healthcare delivery systems are constantly in the process of transformation. There is always a notable improvement in the way a certain healthcare system or organization responds to changes in demand with dynamic forecasts generated through the use of AI as opposed to traditional means. These models rely more on superior algorithms and data analysis procedures to increase on accuracy and flexibility. The proposed CCLR-DL framework introduces deep learning enhancements and statistical modeling while enhancing prediction outcomes' interpretability. This synthesis of the two approaches provided a better prediction of healthcare visits than the individual methods, preparing for shift in demand [15]. Real-time technologies show features by constant assessment of data provided by smart devices to some extent predict conditions such as cardiovascular diseases for individuals. This dynamic prediction capability makes it possible to give proper interventions within the shortest time possible, especially when resources are limited [25]. Time series applied by the AI generates accurate forward estimations of the medical supplies required thus minimizing the cases of stock out or overstock. The identified techniques like SARIMA and LSTM are reported to exhibit better accuracy in forecasting inventory variability so that the healthcare providers can effectively address changes in demand as detailed in Table 1 [2, 8]. Despite approaching unmatched supremacy, conventional techniques factor in where data is scarce or straightforward models are employable. It is therefore possible to conclude that the combination of these approaches can ensure the best outlook for the healthcare demand.

There is also an improvement on the ability to integrate real-time data and AI analytics to support the demand forecasting in the context of healthcare logistics. These technologies help healthcare organizations in managing inventory and to identify and meet the patients' needs satisfactorily. New trends on AI technologies especially the machine learning models with long short-term memory (LSTM) outcompete the traditional means of demand forecasting such as ARIMA as proven by the less errors and higher accuracies from studies conducted in Rwanda [2]. Research studies confirm the use of artificial intelligence in ERP systems in improving the

mean absolute percentage error, real-time stock management and decision-making in different industries encompassing healthcare [26]. Real-time analytics enable swift information transformation, which is helpful for demand oversight as well as inventory optimization, thus ensuring a better client experience [27]. The two technologies represent the integration of IoT with fog computing improve the processing of the generated data in real time and thus improve the reliable healthcare decisions [26]. However, the foregoing technologies present severe benefits that in the following medicinal logistics, challenges like data security and how to integrate these sophisticated technologies form a huge consideration. Solving these problems is crucial for achieving the best results using AI and real-time analytics for demand forecasting.

4 Case Study Insights: Real-World Applications

Using AI to apply dynamic demand forecasting in healthcare logistics presents many practical implications, which are bolstered by a number of case studies. These developments are important in increasing the efficiency, effectiveness, and timeliness of the supply chain processes. Therefore, using the LSTM as an AI model, the RMSE values are 2 which are better than the values obtained from traditional methodologies such as ARIMA in forecasting the medicine demand. They both had a root mean square error of 0 compared to the ARIMA's of 9.35 [2]. The statistical and deep learning-based comprehensive cross-correlation and lagged linear regression deep learning (CCLR-DL) framework enhances the HHcare demand forecasts by a good amount [15]. Some models, for instance the deep reinforcement learning-based dispatching model, on medical supplies during pandemic such as COVID-19 ensures health and economic risks are as well met [28]. AI excellently helps in decision-making and increases the response rate by reducing the level of inventory and improving turnover ratio [7]. Over time, evidence has shown that AI helps to eliminate additional work, for example, automated restocking, as well as to improve the route, thus providing faster delivery and lower operating costs [10]. The principles of AI by integrating into the healthcare logistics can be applied with explicit evidence of gains in efficiency and equally in patients' benefits. This trend is clearly evident from key strategies and outcomes of a number of researches, as it shall be demonstrated further in this paper. Culture and pace are two aspects that can be considered critical success factors for implementing and operating an AI system; culture plays a vital role in building trust to gain support from all the stakeholders [29]. From a survey, it is clear that schedules for training, and improving on technologies are critical in implementing AI as evidenced by the case of emergency medical personnel [30]. AI needs to be applied not only on the surface of patient care processes but also on the organizational level addressing critical operational problems, for example, siloed processes in care delivery and lack of involving patients [31]. The heuristic applications of AI have also enhanced diagnostic capability in the medical imaging and provided virtual care hence enhanced the patients compliance [32]. The study revealing that AI has lessened the administrative restraints on healthcare professions so that they

spend more time caring for their patients will help in advancing the general delivery of the healthcare profession [33].

The application of AI in Lean healthcare logistics and more specifically in demand forecasting also has its advantages and disadvantages that were illustrated by multiple cases. Big data utilization has concerns regarding privacy hence require high level of data management to meet regulatory compliance [10]. Fixed costs are generally high and implementation is often technical, which can phase smaller healthcare providers of the technology [34]. Due to the historical shortcomings of using AI applications for analysis, it has often turned into a human tragedy due to wrong models or overestimation of models, which would increase the use of contextually applicable algorithms. It has been observed that by using complex techniques like LSTM the forecasting accuracy is comparatively more than the traditional methods of ARIMA [35]. Big Data Analytics linked with implementation of AI increases the responsiveness of the supply chain processes [2]. The approach of studying breakdowns applies identifies potential improvements in procedure and technology to reflect specified, actual-world needs [36]. As the provided information proved, AI has the possibility to bring a revolutionary change in the sphere of healthcare logistics. However, the effective implementation of the concept is possible only if the existing issues are considered and the principles of successful application are followed [37].

5 Shaping the Future of Healthcare Logistics

The future of dynamic demand forecasting involving use of AI in healthcare logistics looks promising in that it will enhance the application of Lean methodologies by incorporating even more complex machine learning algorithms. The difficulties, which constitute the focus of this article, shall also grow in relevance as the global population ages and new threats, such as pandemics, emerge, and the needs of healthcare consumers evolve [38]. Deep learning especially the LSTM is foreseen to be a significant enabler of this evolution of Smart Homes. Such models have already shown higher accuracy than traditional methods such as ARIMA, most importantly in handling massive amounts of real-time data thus improving the predictiveness [39]. The application of AI forecasting is perfectly in pace with Lean ideas as all nonessential activities are effectively eliminated and resources are utilized most effectively [40]. Also, it is anticipated that future developments in the field of AI will incorporate real-time data collected by IoT devices and perform real-time analysis of demand data which will further improve the techniques of demand forecasting giving a head start to healthcare organizations to handle dynamic demand patterns [41]. There are certain limitations and challenges that must be addressed in the future studies these include issues of data quality, interoperability with other healthcare systems as well as Model Changes that need to changes to align with real-time environment [42]. Also, as the AI advances, there will be chances to investigate the possibilities of developing the mixed forms of the used methods of forecasting, which will improve

the stability of predictions [43]. AI's application in the field of the healthcare logistics in the future is not just a matter of increased accuracy of measurement and forecasting but the ability of healthcare organizations to respond to patients' current and future needs, which in turn results in better quality of patients' care and thus more efficient functioning of the healthcare system [44]. To do so, it will be necessary to include in the study some techniques that have shown their effectiveness in the industrial field [45]. Examples are equipment maintenance operations [46] or prognostic management [47].

6 Conclusion

The implementation of AI-based demand forecasting models in lean healthcare supply chain is a new step toward managing supply chain challenges. From the case study analysis that was conducted in this study to understand the potential of the AI technologies, it is evident that AI has the potential to change how the healthcare organizations are able to handle dynamic demand patterns. The discovered results draw attention to the fact that a number of factors must be taken into account even if AI shows significant advancement in both the accuracy and speed of the forecasts. The one major issue is that of stability where the AI models used are rigid and do not correspond with the dynamic nature of health care. The challenges occur because demand patterns change owing to disease outbreaks or changes in patient demographics and thus, it becomes necessary to update the AI models. Also, the study underlines the need to check that these systems can easily fit in the existing structures of healthcare supply chains, which is not always possible because of numerous technological and organizational barriers. Moreover, the analysis also reveals that high data quality needs to be sustained as data quality is a significant determinant of the AI models performance. Therefore, if the collected data are not well managed, AI in demand forecasting may be impacted which could result in poor decisions within the healthcare supply chain. It is therefore pertinent to recognize that the utilization of AI to support the functioning of modern supply chains can help improve the forecast and meet the demand that is specific to the healthcare sector. However, it also demands the approach to AI adoption which will address the peculiarities of the healthcare industry such as data issues, model flexibility, and integration. The future research should continue the presented work and address the current challenges and investigate the effects of AI in the field of healthcare logistics in the long run in terms of the scalability and sustainability.

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