Cloud-Enabled Machine Learning: A Framework for Revolutionizing Pharmacy Inventory Management in Nairobi County

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Abstract

This study assesses the impact of cloud-based machine learning on pharmacy inventory management in Nairobi County, Kenya. Traditional pharmacy inventory management results in challenges such as stock-outs and overstocking, which affect financial performance and patient care. The study uses the EOQ and JIT theories to analyze how cloud computing through AWS PaaS and machine learning through the XGBoost algorithm can improve inventory management. A descriptive research design was used, and a target population was 100 pharmacies (65 public and 35 private) in Nairobi County. Structured questionnaires were administered to the pharmacy managers and staff to determine their current practices and perceptions of the proposed cloud-based machine learning framework. Quantitative data was analyzed through regression and correlation analyses. The findings indicated that AWS PaaS improved efficiency by 65%, scalability by 60%, and security by 65%, while XGBoost improved forecast accuracy by 65% and reduced stock outs by 65%. Regression analysis showed a strong predictive power with an R-value of 0.922, and a high p-value of 1.274; showing a statistical insignificance in explaining the variance in inventory management. Similarly, although XGBOOST is a statistically significant predictor (p-value of 0.017), AWS is a statistically insignificant predictor with a p-value of 1.283. Correlation analysis revealed strong positive relationship between the technologies and inventory management. The study concludes that the combination of cloud computing and machine learning can transform the management of pharmacy inventory, including problems that have remained persistent, such as stock-outs and overstocking. The major recommendations are that the proposed framework should be implemented in pharmacies by the management, management should ensure continuous staff training on the use of technologies, and that their performance should be monitored. This research offers an industry-specific, integrated framework to apply advanced technologies for improving efficiency, accuracy, and cost in the pharmaceutical supply chain.

Keywords: *Cloud computing, Machine learning, Inventory management, XGBOOST, AWS PaaS*

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1.0 Introduction

In business administration, inventory management is one of the critical success factors for business operations globally, including in the pharmaceutical industry. The pharmaceutical market around the world was estimated to be $1.42 trillion in the year 2021. Inventory management is one of the key factors in the availability of medication (Wang et al., 2020). In developed countries like the United States and Japan, integrated and highly developed inventory management systems have greatly enhanced healthcare delivery. However, Africa is faced with challenges in pharmaceutical inventory management. The World Health Organization has reported that up to 60% of the health facilities in Africa experience stock-out of essential medicines (Wagenaar et al., 2014).Nonetheless, as per the study by Gelenbe et al., (2022)some countries, such as Nigeria, and South Africa, have adopted digital health solutions to help in inventory management, while many others are still using traditional ways of inventory management.

In Kenya, public and private pharmacies exist to cater for a growing population. However, according to Johnson et al. (2021), many pharmacies use traditional inventory management and the rate of adoption of technology is slow as compared to developed countries. These traditional inventory management methods include manual data input and outdated technology that is error-prone and does not offer real-time data, leading to challenges such as stock-outs or overstocking, which impact negatively the financial performance of pharmacies and the customer satisfaction. For example, a cross-sectional survey conducted by the Ministry of Health in 2019 revealed that 46% of the public health facilities in Nairobi County had stock-out of essential medicines(Gelenbe et al., 2022).

To counter the challenges, this study aims at exploring how cloud-based machine learning can enhance pharmacy inventory systems, with a focus on AWS PaaS as the cloud infrastructure, and XGBoost machine learning. AWS PaaS is efficient in storing and retrieving large inventory datasets while improving the functionality of XGBoost in tracking, forecasting, and restocking. It assists in enhancing the forecast, decreasing stock out and overstock cases, and accelerating data processing and decision-making. This way, the organization can effectively control its inventory, reduce operating expenses, and increase customer satisfaction.

The study's independent variable is cloud-enabled machine learning, which consists of real-time inventory tracking, demand forecasting, and automatic stock replenishment. These indicators are useful for managing the pharmacies so that they can be in a position to order adequate stock for their customers. The large volume of data is stored and processed through AWS PaaS in cloud computing, and the XGBoost algorithm is used to predict sales and stock requirements. On the other hand, the dependent variable is the performance of pharmacy inventory management systems, where inventory turnover, frequency of stock out, and the dollar cost of managing inventory variables are used. This framework has been effective in other areas. Koorowlay & Al-Khannak, (2024)investigated the application of AWS and XGBoost in large manufacturing companies in United States, and observed that stock-out days were reduced by 30% and inventory turnover by 25%. Similarly, Feretzakis et al. (2022) found that the use of cloud computing and machine learning in the hospitality industry in Lagos, Nigeria increased the demand, forecasting accuracy by 40% and decreased expired foodstuffs by 35%. Therefore, this study seeks to resolve the challenge of

insufficiency of traditional pharmacy inventory management in Nairobi County by suggesting cloud-based machine learning inventory management systems.

Statement of the Problem

Stocking in a pharmacy is very sensitive, especially on issues to do with stock-outs or wastage of drugs. Traditional practices lead to issues such as stock ins and outs, which affect the financial revenues and clients' satisfaction. This research aims to fill this gap by constructing a framework that employs AWS PaaS and the XGBoost algorithm to enhance pharmacy inventory management. The problem associated with the systems currently applied in the management of pharmacy stocks are inadequate, leading to a lot of losses thereby compromising the quality of treatment. For instance, stock-outs and overstocking are some of the problems resulting in massive losses that run to millions of dollars. The old inventory management system cannot adapt to the existing market conditions. This inefficiency, therefore results in financial issues, job losses, and low tax receipts, which are all catastrophic to health.

Extant literature explains the benefits of cloud computing and machine learning in various domains, but there is no particular focus on the application of pharmacy inventory management .In particular there is no prior studies that have investigated the integration of AWS PaaS and XGBoost, representing a significant research gap. This aims to enhance the efficiency and accuracy of pharmacy inventory management, potentially transforming operational practices in the healthcare industry. By integrating AWS PaaS and XGBoost, the study offers a scalable and effective solution to a persistent problem, contributing to theoretical knowledge and practical applications in business administration. The findings could inform policy decisions and guide future research, ensuring that pharmacies can maintain optimal inventory levels, reduce costs, and improve patient outcomes.

"The paper found an improvement in the inventory management indices when adopting AWS PaaS and XGBoost."

Purpose of the study

To evaluate the cloud-enabled machine learning as a framework for revolutionizing pharmacy inventory management.

Objectives of the study

i) To identify user requirements for optimizing pharmacy inventory management with cloud-enabled machine learning.

ii) To evaluate the impact of AWS PaaS and XGBoost on pharmacy inventory management.

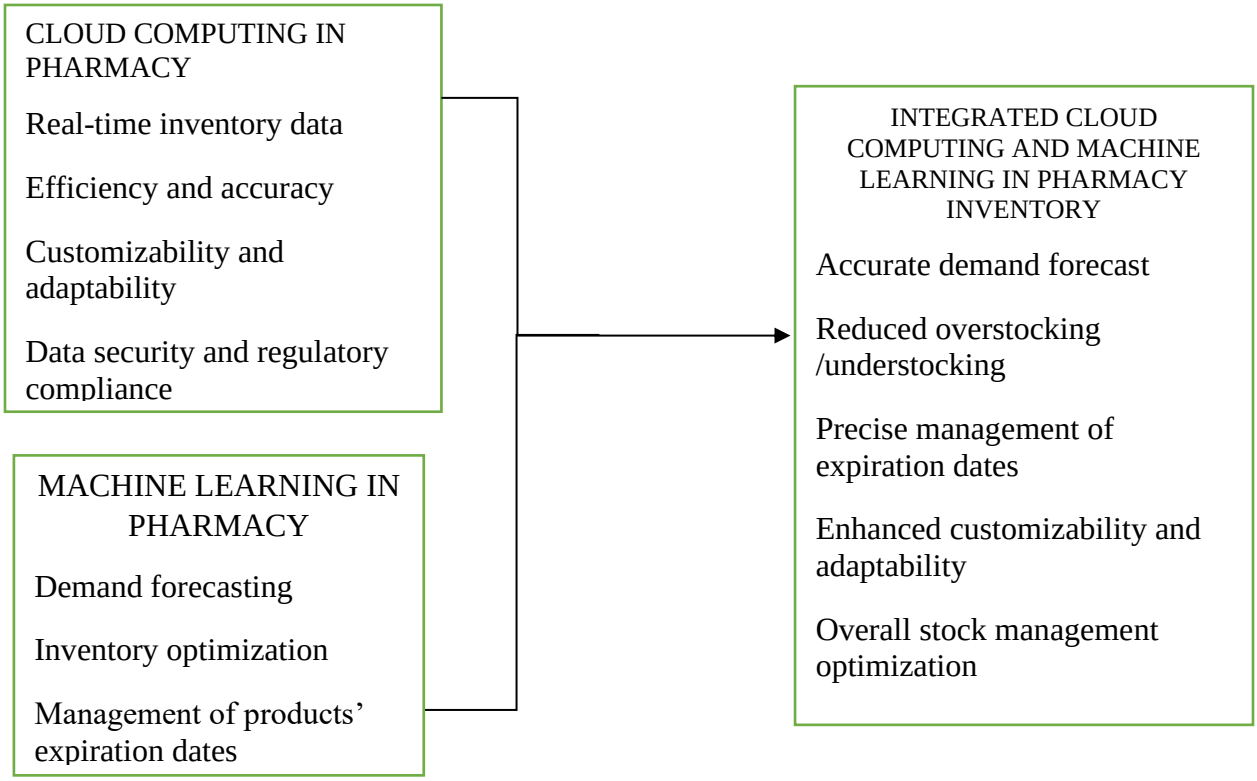
Theoretical Framework

This study is underpinned by the Economic Order Quantity (EOQ) theory. EOQ was established in 1913 to find out the most appropriate order quantity that can minimize the overall cost of inventory holding and ordering (Condeixa et al., 2022). Cloud technologies and machine learning can be used to make real-time EOQ calculations to assist the pharmacies in setting the right order quantity that will allow them to maintain the right stock while avoiding unnecessary costs, thus enhancing performance and efficiency. However, critics opine that the original EOQ model does not capture the current inventory dynamics. The Just-In-Time (JIT) theory which was developed in the 1950s emphasizes the reduction of waste by

procuring materials only when they are required, but is not immune to supply chain threats(Folinas et al., 2017) .The gaps can be filled by integrating cloud computing and advanced analytics in the frameworks of EOQ and JIT, which will allow real-time control, and adjust the stock levels to real sales, thus improving the supply chain.

Figure 1

Conceptual Framework



Empirical Literature

In their study titled "Impact of Cloud Computing on Supply Chain Performance," Fatorachian and Kazemi (2021) quantitatively assessed the effect of cloud computing on supply chain management. The study targeted 100 manufacturing firms in the US, and data was obtained through online questionnaires and analyzed using structural equation modeling (SEM). The findings showed that cloud computing enhanced supply chain visibility and communication with an R-square value of 0. 65; thus, a large amount of variance was accounted for. However, the study did not detail inventory management applications, an aspect addressed in this current research.

Similarly, in Africa, a study on "Application of Machine Learning in Inventory Forecasting "by Lolli et al., (2019)assessed the efficiency of applying machine learning in inventory in 70 retail firms in South Africa. A quantitative research design was used, and data was collected by administering online questionnaires and analyzing them using regression analysis. The results suggested that the use of machine learning algorithms, especially the XGBoost algorithm, made a

positive impact on demand, forecasting with a p-value < 0. 01. Nevertheless, the study did not consider the interaction of the two technologies: machine learning and cloud computing, a gap filled in this research.

Furthermore**,** in Kenya, Mashayekhy et al., (2022) explored the role of advanced technologies in enhancing pharmaceutical inventory management in their study titled "Integrated Continuous Pharmaceutical Technologies". This qualitative study involved interviews with 20 inventory managers from leading pharmaceutical companies in Mombasa County. The analysis revealed that integrating technology in inventory management reduced inventory holding costs and improved stock accuracy. However, the author noted a gap in real-time data analytics, which this study addresses by utilizing cloud computing and machine learning for real-time inventory optimization. The identified literature gaps which this study aims to fill include a lack of comprehensive integration of cloud computing and machine learning tailored to the pharmaceutical industry.

2.0 Materials and Methods

This study employed a descriptive research design to evaluate the impact of cloud-enabled machine learning on pharmacy inventory management. The primary data collection method was structured questionnaires designed to capture detailed insights from pharmacy managers and staff about their current inventory management practices and the potential improvements through cloud computing and machine learning technologies. The research targeted pharmacies within Nairobi County, a significant hub for pharmaceutical activities. The population was split into numerous subgroups or strata, such as types and sizes of pharmacies. With this stratified population, a random sampling technique was employed to get a sample of 100 pharmacies; 65 from the public sector and 35 from the private sector. Simple random sampling technique assists in the generalization of the results since it ensures that the sample is good enough to represent the entire population (Turner, 2020). The questionnaires consisted of close-ended questions to obtain numerical responses, and also open-ended questions to obtain more elaborate responses regarding respondents' perceptions.

The quantitative data was subjected to analysis to test the level of significance of the Cloud-based Machine Learning on inventory management results. In particular, regression analysis and correlation analysis were employed to compare the independent and dependent variables. Data analysis was done using Statistical Package for the Social Sciences program (SPSS). This software was chosen as it provided enhanced options for graphical output, self-generated reports, and an integrated data pre-processing facility. The analyzed data was presented in tables and figures to enhance clarity and ease of understanding. To maintain anonymity and confidentiality of participants, data was stored using AWS 'cloud' services, which has strong security measures, including encryption at rest and in transit. Access to the data was controlled through role-based access controls, and only anonymized data was used in analysis. During analysis, all identifying information were removed from the data, with participants coded by unique identifier, and no other personal identifiers were contained in the data files.

3.0 Results and Discussion

The study achieved a 100% response rate, with all 100 participants completing the survey. The respondent demographics revealed a diverse group of pharmacy professionals. The majority (55%) were aged 26-35 years, with a slight female majority (55%). Professionally, 40% were pharmacists, followed by pharmacy

technicians (30%) and inventory managers (15%). Experience levels were well-distributed, with 55% having 3-10 years of experience. Most respondents (60%) worked in retail pharmacies, followed by hospital pharmacies (25%).

Table 1

User requirements of the pharmacy inventory management

Challenges in inventory

Primary challenges with inventory management	Respondents	%
stock-outs	15	15
Overstocking	12	12
Expiration management	26	22
Demand forecasting	18	18
Supplier management	22	26
Data accuracy	7	7

While examining the primary challenges pharmacies face in inventory management, findings in Table 1 reveal expiration management emerged as the most significant issue, with 26% of respondents citing it as a concern. This was followed by supplier

management (22%), demand forecasting (18%), and stock-outs (15%). Interestingly, only 12% of respondents identified overstocking as a primary challenge, while data accuracy was the least reported issue at 7%. These results highlight the critical importance of managing product expiration dates in the pharmacy setting and the complexities involved in supplier relationships, and accurately predicting demand. These results align with a study by Nguyen et al. (2022) who examined pharmaceutical supply chain and inventory management in India in 2013. Their results showed that expiration, supplier, and demand are some of the challenges facing pharmacy inventory.

Regarding inventory update frequency, most pharmacies (35%) reported updating their inventory weekly as per Table 2

Table 2

Frequency of updating current inventory systems

Management Frequency of currently updated inventory systems	**Respondents**	**%**
Daily	15	15
Weekly	35	35
Monthly	20	20
Quarterly	5	5

Daily updates were performed by 15% of respondents, while 20% opted for monthly updates. Only 5% of pharmacies updated their inventory quarterly, suggesting that most recognize the need for relatively frequent inventory assessments.

When asked about desired features in an inventory management system, respondents showed strong interest in predictive analytics and customizable reporting, as shown in

Table 3.

Table 3

Preferred features in the proposed framework

Preferred features in the proposed framework	Respondents	%
Real-time tracking	17	17
Automated reordering	12	12
Predictive analytics	23	23
Integration with suppliers	7	7
Mobile access	18	18
Customizable reporting	23	23

Mobile access was also a popular feature, chosen by 18% of respondents. Real-time tracking was desired by 17%, while automated reordering was selected by 12%. Surprisingly, only 7% of respondents expressed interest in integration with suppliers. These results are similar to those of a recent survey conducted by TechLogix Research on 200 supply chain managers, where the two most important features were predictive analytics and the capability to customize the reports (Koorowlay & Al-Khannak, 2024).

The study also investigated current demand forecasting methods employed by pharmacies. Results are shown in Table 4.

Table 4

Current methods forecast

Current methods forecast demand	Respondents	%
Manual analysis	40	40
Basic software	35	35
Advanced analytics	15	15
Don't forecast	10	10

Manual analysis emerged as the most common approach used by 40% of respondents. Basic software was utilized by 35%, while only 15% reported using

advanced analytics for demand forecasting. Notably, 10% of pharmacies indicated they do not forecast demand, suggesting an area for improvement. These results are in line with a previous cross-sectional survey conducted in 2022 with 300 independent pharmacies in North America, to explore the use of demand forecasting (Atiga et al., 2023). Outcomes revealed that manual review dominated and was closely seconded by basic software application. The study also revealed that some pharmacies had no demand forecasting at all.

Table 5 shows the biggest pain points in managing expired products.

Table 5

Biggest pain point in managing expired products

The biggest pain point in managing expired products	Respondents	%
Identifying near-expiry items	40	40
Disposal process,	30	30
Tracking expiration dates	20	20
Returning to suppliers	10	10

Identifying near-expiry items was reported as the most significant challenge by 40% of respondents. The second most common issue was the disposal process, cited by 30% of pharmacies. Tracking expiration dates and returning products to suppliers were less prominent concerns, mentioned by 20% and 10% of respondents respectively.

Impact of AWS PaaS and XGBoost on pharmacy inventory management

Several key findings emerged based on the survey results evaluating the impact of AWS PaaS and XGBoost on pharmacy inventory management (table 6). AWS PaaS received positive feedback across various metrics: 65% of respondents agreed that it enhances efficiency, 50% were neutral regarding cost reduction (which indicates room for further research), 60% acknowledged its scalability benefits, and 65% appreciated its security improvements. Additionally, 55% viewed its integration capabilities, 65% noted enhanced collaboration, and 70%, which is the highest, agreed on improved reporting capabilities. The results were in agreement with a study on CloudTech Innovators' whose survey included 150 pharmacies that implemented cloud-based inventory management systems. The study revealed that the pharmacies that adopted AWS PaaS noted a dramatic increase in its inventory accuracy and effectiveness. Some of the benefits mentioned by users included real-time data access, scalability and integration as some of the key aspects that support efficient pharmacy inventory management.

On the other hand, opinions regarding XGBoost were also positive on its role in improving forecasting accuracy, 65% recognized its effectiveness in minimizing stock issues, and 65% found it capable of managing seasonality well. However, opinions were mixed on its impact on waste reduction, where 60% agreed to its reduction of waste but 30% were neutral. This shows that though the technology is effective, it needs improvements on the aspect of waste reduction. Regarding operational aspects, 60% agreed on its effectiveness in optimizing

turnover and managing multi-location inventory, while 35% were neutral on the training required. Overall, 70% of respondents strongly agreed on the combined effectiveness of AWS PaaS and XGBoost in improving pharmacy inventory management, highlighting their complementary roles in enhancing operational efficiency and decision-making processes.

Table 6

Impacts of XGB boost and Aws on inventory management

statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
AWS PaaS improves efficiency	5	10	20	40	25
AWS PaaS reduces costs	8	12	30	35	15
AWS PaaS provides scalability	5	10	25	40	20
AWS PaaS improves security	5	10	20	45	20
AWS PaaS enables integration	5	10	30	40	15
AWS PaaS enhances collaboration	5	10	25	40	20
AWS PaaS improves reporting	2	8	20	50	20
XGBoost enhances forecasting	3	7	25	45	20
XGBoost minimizes stock issues	2	8	25	50	15
XGBoost reduces waste	3	7	30	45	15
XGBoost requires training	10	15	25	35	15
XGBoost handles seasonality	2	8	25	45	20
XGBoost optimizes turnover	3	7	30	45	15
XGBoost manages multi-location	5	10	25	40	20

Statistical Analyses

Although, the regression analysis model shows a strong predictive power with an R-value of 0.922, R-squared of 0.85, the high p-value of 1.274 shows a statistically insignificance in explaining the variance in inventory management as shown in table 7. Similarly, although XGBOOST is statistically, significant predictor p-value 0.017 (p-value < 0.05), AWS is a statistically insignificant predictor with a p-value of 1. 283. However, AWS larger coefficient (0.67) than XGBOOST (0.13), suggests that it has a stronger influence on inventory management. The model's overall significance (F-statistic: 1974.68, p-value: 1.274) is extremely high. These results show the effectiveness of both technologies in improving pharmacy inventory management, with AWS showing a particularly substantial impact.

Table 7

Regression Analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.922	0.85	0.85	0.339

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	454.513	227.2565 6	1974.68 4	1.274
Residual	696	80.099	0.115085		
Total	698	534.612			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.686	0.049	13.991	2.245	0.59	0.783
XGBOOST	0.135	0.057	2.388	0.017	0.024	0.2463
AWS	0.67	0.06	11.135	1.284	0.55	0.788

The correlation analysis results show strong positive correlations across all variables as shown in table 8. XGBOOST and AWS have an extremely high correlation (0.978), indicating they are closely related or potentially measuring similar aspects of technology implementation. XGBOOST and AWS show strong positive correlations with inventory management (0.907 and 0.921, respectively).

Table 8

Correlation Analysis

		XGboost	AWS	Inventory management
XGboost	Pearson Correlation	1	.977**	.908**
	Sig. (2-tailed)		.000	.000
	N	700	700	700
AWS	Pearson Correlation	.977**	1	.922**
	Sig. (2-tailed)	.000		.000
	N	700	700	700
Inventory management	Pearson Correlation	.908**	.922**	1
	Sig. (2-tailed)	.000	.000	
	N	700	700	700

AWS has a slightly higher correlation with inventory management than XGBOOST, aligning with the regression analysis findings. These strong correlations suggest that both technologies are highly associated with improved inventory management outcomes. The findings agree with a study by Zohdi et al. (2022) who found high positive correlations between machine learning algorithms and enhanced demand forecasting in retail firms, with the firm's XGBoost inventory accuracy model of 0.893.

4.0 Conclusion

This research explored the transformative impact of cloud-enabled machine learning on pharmacy inventory management, specifically using AWS PaaS for cloud infrastructure and XGBoost for predictive analytics. These objectives were met through a quantitative approach, including questionnaires targeting pharmacy managers and staff within Nairobi County. The study results enriched the existing literature by implementing AWS PaaS and XGBoost in inventory management. Past studies failed to distinguish the pharmaceutical industry and did not pay adequate attention to the combined effects of cloud computing and machine learning. This research has filled these gaps by providing quantitative measurements of the impact of these technologies on the forecast accuracy, reduction in stock-out rates, and inventory turnover. The theories of EOQ and JIT were used to demonstrate how through machine learning is made possible through cloud computing. The number of orders was reduced and the inventory was restocked to meet the immediate demand and not a cent more. The study findings indicated an improvement in the inventory management indices when adopting AWS PaaS and XGBoost. However, the regression analysis indicated that XGBoost was statistically significant in accounting for changes in inventory management, while AWS was statistically insignificant predictor due to the high p values, despite the positive correlation between the two technologies with regard to pharmacy inventory management.

5.0 Recommendations

Based on the findings which demonstrated the positive impact of using machine learning and cloud computing in pharmacy inventory management, this study recommends that Pharmacies should adopt AWS PaaS and XGBoost to enhance the management of their inventories by processing real-time data and offering forecasts. However, the framework should be tested regularly to identify its impact on pharmacy inventory management as the high P values suggest statistical insignificance, especially in the use of AWS. Pharmacy management should also ensure that their staff are continuously trained on how to use cloud-based inventory management systems and how machine learning algorithms can be used to forecast demand. Additionally, pharmacy staff should use these technologies to manage stock in the most efficient manner to avoid stock-outs and overstocking, while at the same time ensuring real-time tracking. Management should also ensure that performance data is constantly analyzed and changes made in the inventory management processes as and when necessary.

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