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Inventory Management Using Genetic Algorithm

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Abstract:
Background*: The success of any business hinges on its ability to meet customer expectations. Meeting customers' expectation has to do with the ability to deliver the right products and services to the right place and people and it is strongly reliant on an effective and functional inventory system. Inventory control and management process has evolved as a critical requirement for business success in view of the rising demand from customers, flourishing merchandise portfolios and broadening supply chains. On this note, this paper presents a Genetic Algorithm system for inventory control and management.*
Materials and Methods*: The conceptualization of the system adopted measures for integrated access control, user authentication, authorization and confidentiality as well as encryption-based data integrity, availability and non-repudiation. The operational flow of the proposed system uses the concept of genetic algorithm for proven analysis of the existing records for the attainment of functional and fruitful inventory management. The analysis begins with numerous orders whose chromosome generation and confirmation is through some previous order sets and taking the stock levels for the existing delivering sequence for the various products.*
Results*: Results from the experimental study of the system confirmed its adequacy for achieving result-oriented inventory control and management operations. The proposed system also addressed the problems of missing platform, high error rates and mathematical complexities inherent with some similar models.*
Conclusion: *The proposed* inventory control and management platform is suitable for effective, dynamic and result-oriented inventory control and management.

Key Word*: Inventory, stock, genetic algorithm, users' expectation.*

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I. Introduction

Inventory is the goods held for sale in the course of business. It is also the goods being held for manufacturing or selling purposes. It is a very important and vital component of a company and represents a significant source of future profit. It is composed of the raw materials, consumable items, components and spares, semi-processed materials, fuel and lubricants, finished goods and other items that are essential to be stocked for the smooth running of the organization [1-4]. The key role of inventory is to guarantee supply and maintain operational continuity [5]. Inventory are classified into cycle stock, in-transit stock, safety or buffer stock, speculation stock, seasonal stock and dead stock [6]. Inventories are kept for a number of reasons including economies of scale, balancing supply and demand, specialization protection from uncertainties and season demand [7]. Existing inventory techniques include ABC Analysis, Just-in-Time (JIT), Material Requirement Planning (MRP), Economic Order Quality (EOQ) and Minimum Safety Stock (MST). ABC analysis classifies the most important items (highest price) into class A, those of intermediate importance (middle price) are classified as class B while the rest (low price) are classified into class C. The JIT Method is based on the premise that the firm keeps a minimum level of inventory on hand, hoping for a timely delivery from the supplier. This method helps in ensuring continuity in the line of production. The MRP method is a set of procedures for converting forecast demand for a manufactured product into a schedule for obtaining components, sub-assemblies and raw materials and it is useful for preventing unbalanced lot sizing. EOQ Model is the basic model for inventory control in production companies and it is based on unrealistic assumptions in which the demand is assumed to be constant. This form of assumptions subject EOQ to unattractiveness in most industrial settings. The MST method is used to ascertain the safety level in inventory in view of the fact that smaller safety level implies greater risk of stock outs [8].

Inventory control is the coordination of the procurement and utilization of available materials or resources. It is also concerned with getting the right inventory and quality in place at all time [5, 9]. Inventory management involve the organization, planning, sourcing, purchasing, moving, storing and control of inventories in a most advantageous style towards achieving customers' satisfaction with very minimal cost [10-11]. It is important for achieving organizational effectiveness and avoiding exceeding low or high stock level. In manufacturing, stock-out may lead to a halt in production as well as loss of patronage. It is also good for informing managers of the level of good to re-order, knowing when and how to re-order, determining the frequency of order, establishing the most accurate safety stock, achieving organizational financial growth and increasing return on total assets [12-13]. According to Rosenblatt [14], the cost of inventory is always an integral part of the price paid by the consumer and it includes ordering cost, carrying cost and setup cost. Basically, there are four types of inventory control systems, namely Manual Inventory Management System (MIMS), Barcode Technology (BCT), Radio Frequency Identification (RFID), Warehouse Management System (WMS) and Near Field Communication (NFC) tag. The MIMS is applicable to small scale businesses such that at the start of each week, the owner manually counts products and materials that are on hand and enters the values in the spreadsheet and also enters expected usage based on existing orders. The BCT creates a unique set of numbers or characters for accurate and efficient identification of item. When a barcode is read at the point of sale, inventory sales data is immediately read and sent to a broader system that maintains usage statistics. The RFID technology uses tag that emits information to a long-range reader. While active RFID technology uses fixed tag readers for real-time monitoring of the movement of an item in and out of stock, passive RFID technology uses handheld readers to monitor inventory movement. The WMS is a key part of the supply chain and involves the management of storage of products within the confinement of a warehouse. NFC tag is used to get information on item′s departure or arrival based on close contact communication [15-17].

The techniques for inventory control system include machine learning, fuzzy logic, neural network, predictive modeling, dynamic programming, deep reinforcement learning, artificial intelligence and genetic algorithm [18-28]. Genetic Algorithm (GA) is a random application of practical knowledge for maximization and it is primarily premised on an initial population of possible solutions to a problem each with peculiar attributes that established its fitness for membership. The highest fit members attain higher probability of mating than lesser fit members to create offspring with a noteworthy likelihood of retaining the much desired characteristics of their ancestors. GA is highly effective for establishing peak solutions to numerous problems since it is devoid of the shortcomings of most traditional methods [29]. GA-based inventory control is frequently used in mathematical, management and system sciences as well as industrial and manufacturing engineering.

In [5], ABC analysis, critical value analysis and Just-in-Time production model was used for the allocation of time and money as well as dealing with multiple product lines and stock-keeping units for efficient and effective inventory control and management. The model established analytical way of relationship between inventory control and performance but it is not useful with inappropriate storage warehouses. Serhii [9] established a model that is based on fuzzy logic set theory for inventory management. The model combines artificial intelligence and neural network to handle imprecision and uncertainty as a quantitative way of solving inventory control problem but relies significantly on assumption of a simple structure of the production process. A web-based inventory control system using cloud architecture and barcode technology is presented in [30]. The system supports log-range wired scanning of barcode but readability of the tag is hampered with increase in the size or damage of the barcode tag. In [31], web-based intelligent inventory management system using Java Remote Method Invocation (JRMI) with a secure socket layer (SSL) is presented. The system integrates multiple systems to providing efficient coordination and monitoring for inventory performance optimization, though its intelligence places premium on fuzzy logic more than genetic algorithm.

Boute *et al.* [23] presented a Deep Reinforcement Learning (DRL) model for inventory control in which the decision process hinges on Markov theorem and Neural Networks (NN). The NN was employed as an approximate numerical approach for optimizing the inventory problems which are modeled as Markov decision problems. The model focuses on theory building and blending of numerical approach of DRL with analytical results showing its usefulness for inventory control but gives no consideration to operations management and management science. Praveen *et al.* [21] presented an ensemble decision tree machine learning algorithm for inventory management. The model utilizes XGBoost which constructs the decision trees based on the error factor obtained from the previous tree for prediction and implementation of large amount of data. Experimental results showed the applicability of the model for maintaining inventory with minimized manual labor as well as its inability to incorporate categorical embeddings. The application of artificial neural networks and deductive quantitative modeling in supply chain management and optimization of inventory level towards improving the ordering process is presented in [28]. The focus is to establish the suitability of NN for prediction and enhancing the ordering system. It was established that ANN models are very useful for inventory management and handling lot-sizing problem but no consideration for ordering based on predicated demand.

From the existing knowledge, it could be inferred that little or no attention has been paid to the application of genetic concept as a tool for achieving adaptive and dynamic inventory management. The existing inventory control and management models suffered due to complexity with growth in stock, too much assumptions, vague strategy, lack of consideration for ordering based on predicated demand among others. This study was therefore motivated by the need to establish an inventory management model that promotes adaptive and intelligent inventory management, establishes effective and efficient ordering strategy as well as helps meet users' satisfaction. The objective of the study was to formulate a genetic algorithm model that promotes merit-based inventory management as well as addresses some of the limitations of the existing related works. The proposed model uses the genetic operations of selection, crossover and mutation to deliver a cognitive and rational inventory control and management mechanism. The experimental data was obtained from the ordering and inventory actions of Sharagbuyi Enterprise, Akure, Nigeria between January 2020 and March 2021. The dataset was of size 600 and featured attributes such as item, name, cost price, unit price, unit item, stock level, restock level among others. Notably, the study established the usefulness and relevance of genetic algorithm for attaining satisfactory and low error rate inventory control and management. The contributions of the new model include specific application of genetic algorithm to inventory control and management, provision of an adaptive and dynamic inventory structure, addressed the problems of missing platform, high error rates and mathematical complexities inherent with some similar models and established an inventory control and management platform suitable for referencing in future research. The following sections present the proposed model, experimental study and the conclusion drawn from the research.

II. Inventory Management Using Genetic Algorithm

The main components of the proposed generic algorithm-based system are presented in Figure 1. Security is a key issue in the development of any system hence the conceptualization of the system adopted measures for integrated access control, user authentication, authorization and confidentiality as well as encryption-based data integrity, availability and non-repudiation.

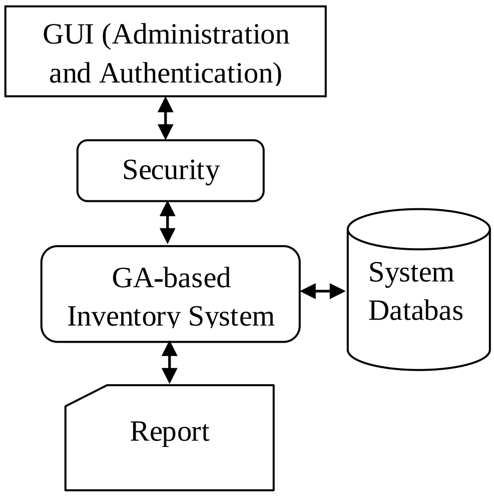


Figure 1: Architecture of the proposed

Genetic Algorithm (GA)

The delivery sequence of factories, distribution centers, suppliers and retailers often possesses a number of vendors. A typical delivery sequence consisting of Manufacturer, Merchant and Vendor is shown in Figure 2.

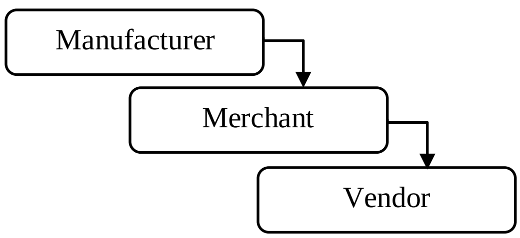


Figure 2: Members of the supply sequence

The Manufacturer produces and maintains massive stock for meeting the requirements of the Vendor and also ensures the stock level guarantees adequate supply to the Merchant. The focus of the delivery sequence is to adequately forecast the maximum stock level and the expected revenue from the orders while guiding against over stocking or under stocking. This implies that at each level of the sequence, the pre-stock levels for the Manufacturer, Merchant and Vendor are predetermined as necessary ingredient for determining the maximum stock requirement. The concept of the GA for the management of the delivery sequence is illustrated in Figure 3 [32].

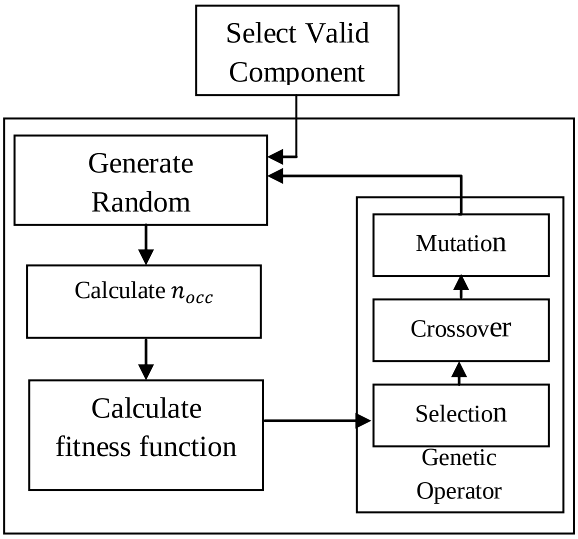


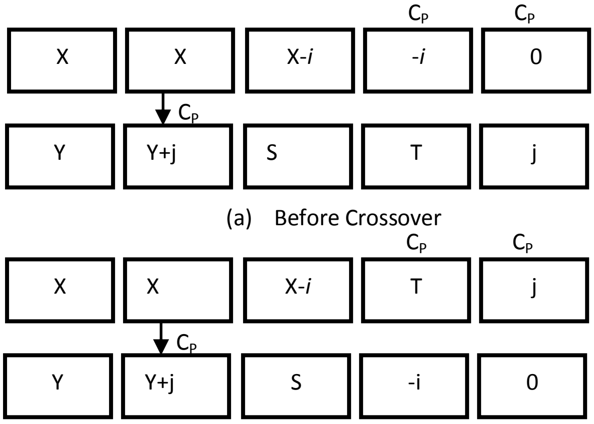
Figure 3: Genetic Algorithm flow for the proposed system

The operational flow of the GA system requires effective and efficient analysis of the existing records to attain workable and result-oriented inventory management. The analysis commences with the variety of orders whose confirmation is via previous months ordering set. The stock levels for the existing delivering sequence are taken for the various products. If p number of products are chosen for the analysis, the stock levels for the p products and for every component of the sequence for the month under consideration are taken. Based on the obtained stock level, a random population of take-off chromosomes is formed. These chromosomes are taken through the process of genetic operations of selection, crossover and mutation while the ensuing chromosome is derived consequent to the application of crossover and mutation. For the iteration value of v, the ensuing chromosome progresses towards the fittest chromosome subsequent to every sequential implementation. Consequently, at the end of the n^{th} sequential implementation, there exist a chromosome and a fitness function adjudged the best.

Each component of the order constitutes the gene that is generated based on randomization. The chromosomes for the delivery sequence are derived from the order at various levels and it is used for performance evaluation. The evaluation of fitness function is based on a specific objective function that lists the maximal solution for ranking certain chromosome against all the other chromosomes. The chromosomes in the neighborhood of the maxima chromosome are allowed to amalgamate their datasets to generate an offspring that is adjudged superior to the preceding ones. The fitness function is derived from:

$$f(i) = \log\left(1 - \frac{n_{occ}(i)}{n_{tot}}\right), 1,2,3, \dots \dots \dots . . n \qquad (1)$$

$n_{occ}(i)$ is the count of the occurrences of the chromosome i in the record set and n_{tot} is the total number of proceedings. The fitness function ranks the randomly generated chromosomes and subjected them to selection, crossover and mutation. The selection operation focuses on obtaining the most outstanding (fittest) chromosome based on the ranking of the calculated fitness for every chromosome. The selected chromosome is then presented for a single function crossover in which there is a swap between the genes that are located right of the cross over point in the two chromosomes to obtain two new chromosomes as shown in Figures 4.



(b) After Crossover

Figure 4: Chromosome before and after crossover

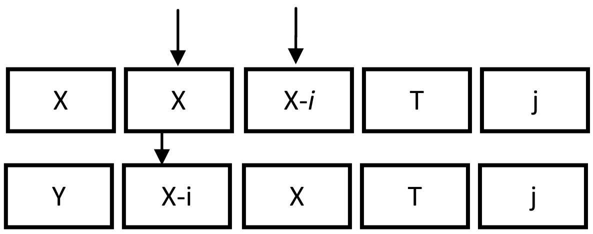


Figure 5: After Mutation

Chromosomes from the crossover operation are subjected to mutation via a random generation of two points and swapping of the genes leading to dual but different chromosomes and shown in Figure 5. Mutation is followed by the generation of a separate chromosome with a redo operation for the dual chromosomes having the most outstanding fitness function. Each of the operation leads to a most outstanding chromosome which is appropriate for maximal solution to the inventory control problem. The increase in the number of the operation leads to proximity among the expected and actual solutions.

An inventory problem at time T for inventory level for dealer *d* at period t is given as x_t^d. If P(u) is the probability of observing u units of demand, the customer's demand observed by dealer *d* in period t will follow a Poisson distribution with λ_d^t. Right from the beginning, the Manufacturer assigns $\sum_{s=1}^{N} q_t^s$ units to N dealers while the replenishment is delivered at ℓ periods preceding this decision. This leads to a further assumption that other suppliers have limitless sources of supply or operate at very high service levels with insignificant delays from the supplier. A phenotype space is adopted for the GA based on the conclusion that P is a set of all combinations of ordered quantities for period T. The chromosome representing the dealers' highest order for the period takes the form of the sequence:

$$\ell = q_1^1 q_2^1 \dots q_T^1 q_1^2 \dots q_T^2 \dots q_1^d \dots q_N^d \tag{2}$$

q_t^d is the direct value representation of the replenishment quantity. Each chromosome is a string consisting of d×N genes, where N is the number of periods. Each gene, takes on any value in the range [0, C_d], according to the inventory carrying capacity of dealer *d*. Each chromosome consists of all decision criteria in the model. If the inventory on hand exceeds the capacity level for the given allocation quantity at any period, q_t^d is suppressed to provide the post-allocation peak realistic inventory level. Consequently, the chromosomes are kept in the practicable sphere devoid of extra constriction. The fitness value of a given solution (f), represented by a chromosome ℓ, is the minimum expected aggregate cost of the system. The aggregate cost derived for any chromosome TC(ℓ) is presented in Equation (2) and the related sub-Equations (3) - (6) give the recursive derivations for ordered conclusion for the lot sizes (q^d *and* Q) over the periods ℓ *and* ℓ_0.

$$TC(\ell) = \sum_{d=1}^{N} g_1^d\left(x_1^d, q_{1-\ell}^d, \dots q_0^d\right) + f_1\left(y_1, Q_{1-\ell_0}, \dots Q_0\right) \tag{3}$$

For t = 1, …, T-1:

$$g_t^d\left(x_t^d, q_{t-\ell}^d, \dots q_{t-1}^d\right) = \left\{\delta q_t^d + L(x_t^d) + \sum_{u=0}^{\infty} g_{t+1}\left(x_t^d + q_{t-\ell}^d - u, q_{t-\ell+1}^d, \dots, q_t^d\right) P(u)\right\} \tag{4}$$

Hence, at t = T,

$$g_t^d\left(x_T^d, q_{T-\ell}^d, \dots q_{T-1}^d\right) = \left\{\delta q_T^d + L(x_T^d)\right\} \tag{5}$$

Such that for t = 1, …, T-1,

$$f_t(y_t, Q_{t-\ell}, \dots Q_{t-1}) = \min_{Q_t \geq 0}\{\delta Q_t + H(y_t, \sum_{n=1}^{N} q_t^n) + f_{t+1}(y_t + Q_{t-\ell_0} - \sum_{n=1}^{N} q_t^n, Q_{t-\ell_0+1}, \dots, Q_{t})\} \quad (6)$$

Which also implies that for t = T,

$$f_T(y_T, Q_{T-\ell_0}, \dots Q_{T-1}) = \left\{\delta Q_T + H(y_T, \sum_{n=1}^{N} q_T^n)\right\} \quad (7)$$

The system flowchart is presented in Figure 6.

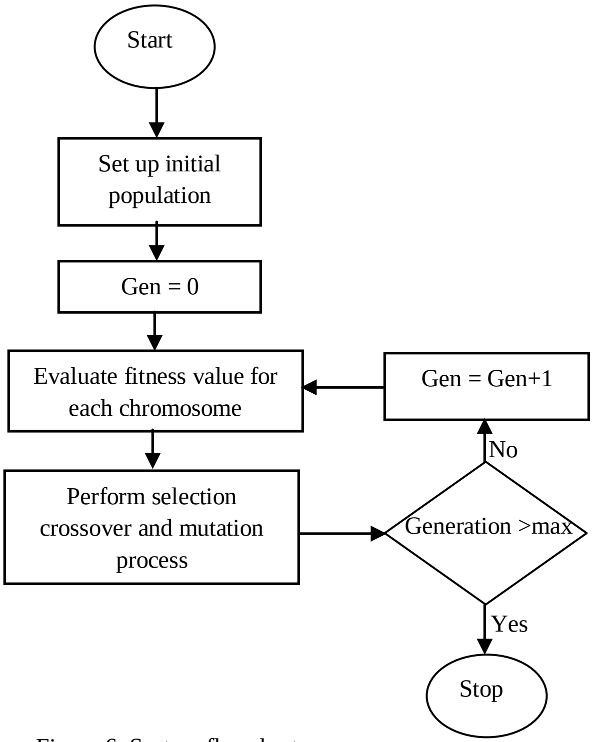


Figure 6: System flowchart

III. Experimental Study

The experimental study of the proposed GA model for inventory management was carried in Window 10 environment on HP laptop with 4GB RAM and 1TB HDD. Microsoft Visual Studio Code – Integrated Development Environment, Google chrome browser, PHP and Matlab 2021a served as frontends while MySQL database from Wamp Server 2.2 provided the backend. Case study of inventory control and management of a standard inventory dataset was used to test the practical function of the proposed system. The Dataset was based on the ordering and inventory activities of Sharagbuyi Enterprise, Akure, Nigeria between January 2020 and March 2021. The dataset was of size 600 and featured attributes such as item, name, cost price, unit price, unit item, stock level, restock level among others. The analysis flow was initiated by the selection of orders whose validation was done over the order for the period under consideration. The stock levels at the different supply chain members were held for different products. At each member of the chain throughout the period, the stock levels for the products formed the experimental data which is typically shown in Table 1.

Table 1: Subset of the experimental dataset

Order Products	Order Amount	Net Total	Amount Paid	Discount	Profit
001	1700	1700	1690	-10	0
002	700	709	300	400	9
003	700	707	707	-450	7
004	700	707	710	0	7
005	600	600	550	-3	0

006	1070	1070	1000	50	0
007	470	564	564	70	94
008	550	550	500	0	0
009	950	950	900	50	0
010	650	970	990	50:	7

Random population of initial chromosomes was formed from the experimental data of size 600. These chromosomes were subjected to the genetic operators, crossover and mutation. At the end of 100 iterations, the resultant best fit chromosome '1541.36 1584.07 542.16 341.18 2.64' was obtained. The fitness function is presented in Figure 7. The fitness function presents the assessment of the closeness of the solution created by the defined sets of chromosomes and the preset ones. As shown in Figure 7, the fitness function quantitatively expressed the measure of the fitness of the obtained solution to the inventory control problem. The system's feedback option was used to gauge the performance of the inventory system. Based on the 600 orders, the practical function of the inventory system was investigated using precision, recall, F1 score, specificity and balanced accuracy. Precision measures the ratio of correctly given positive assessment of the system while recall measures the ratio of correctly given positive rating to all the positive ratings. The F1 score combines the results of precision and recall and just like the previous two, plays more emphasis on the positive ratings. Specificity is the True Negative Rate (TNR) of the rating. For balanced accuracy of the system which gives more reliable accuracy for imbalanced data sets, True Positive (TP), False Positive (FP), False Negative (FN) and True negative (TN) were considered. TP is the number of cases correctly obtained as true, FP represents total cases that are incorrectly obtained as true, TN connotes the sum of properly false cases and FN gives the total cases that are incorrectly false.

Table 2 presents the obtained confusion matrix of the system's feedback for four different sets of order, which presents positivity for the rating values greater than or equal to 3 and negativity for the rating values smaller than 3. The summary of the obtained precision, recall, F1 score, specificity and balanced accuracy for the order sets are also presented in Table 3.

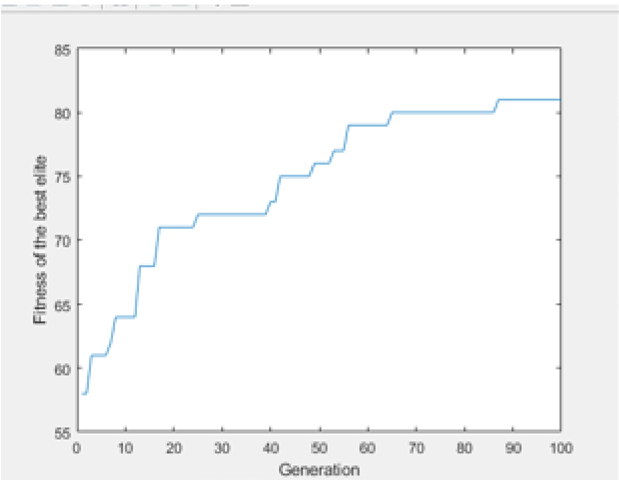


Figure 7: The fitness function

Table 2: Confusion Matrix

Dataset size	Confusion matrix	Positive case by agent (rating ≥ 3)	Negative case by agent (rating <3)
150	Positive case (rating ≥ 3)	TP (114)	FP (19)
	Negative case (rating <3)	FN (6)	TN (11)
300	Positive case (rating ≥ 3)	TP (238)	FP (30)
	Negative case (rating <3)	FN (12)	TN (20)
450	Positive case (rating ≥ 3)	TP (329)	FP (30)
	Negative case (rating <3)	FN (12)	TN (20)
600	Positive case (rating ≥ 3)	TP (379)	FP (104)
	Negative case (rating <3)	FN (56)	TN (61)

Visual inspection of the values presented in Table 3 reveals that in most cases, the precision, recall, specificity and balance accuracy recorded for the system grow with the number of orders. This shows the performance of the GA system grows with increase in the number of orders. Table 4 presents the comparative analysis of results from the research with results from the implementation of the algorithms presented in other similar researches using the experimental dataset. It is revealed that the new system recorded higher values for all the metrics, which buttressed its presentation for use as a reliable inventory control and management system.

Table 3: Summary of the results for the evaluation metrics

Order Size	Precision (%)	Recall (%)	F1 Score (%)	Specificity (%)	Balance Accuracy (%)
150	78.5	87.1	83.0	37.0	62.0
300	86.1	91.8	89.9	42.0	67.1
450	88.8	95.2	91.9	40.0	67.6
600	89.7	95.7	93.1	37.0	68.0
Average	85.8	92.5	89.5	39.0	66.2

Table 4: Comparative analysis

Research	Precision (%)	Recall (%)	F1 Score (%)	Balance Accuracy (%)
Obiri *et al.*, [5]	84.5	74.0	72.0	60.0
Thomas *et al.*, [30]	73.0	69.0	68.0	42.0
Abisoye *et al.*, [33]	85.0	84.0	81.0	58.0
Proposed system	85.7	95.0	90.1	66.0

IV. Discussion

The development of a genetic algorithm-based inventory control and management system that prioritizes adequate optimization of the inventory product, consequential revenue and stock level has been presented. The research adopted genetic algorithm technique that emphasized selection, cross over and mutation for aiding critical decisions on inventory as well as achieving fast, accurate and light-weight operations. The proposed system filters information from the existing orders as a chromosome to generate low stock level for the expected revenue. The operational sequence of the system requires effective and efficient analysis of available record towards achieving functional and dynamic inventory control mechanism. The analysis is based on some known orders whose confirmation is through some existing ordering sets. The stock levels for the existing delivering sequence are also taken for the diverse products. An arbitrary population of take-off chromosomes was established for the stock level. The chromosomes were subjected to genetic operations to obtain a new chromosome which progresses towards the fittest chromosome in a sequential implementation. The evaluation of fitness function is based on a specific objective function that lists the maximal solution for ranking certain chromosome against all the other chromosomes. The chromosomes in the neighborhood of the maxima chromosome were allowed to amalgamate their respective datasets to generate an offspring that is adjudged superior to the preceding ones.

V. Conclusion

Specifically, this paper presents the application of genetic algorithm to inventory control and management. Its implementation with dataset on inventory control and management established its adaptive and dynamic capabilities as well as its ability to address some of the limitations of some existing works. The investigation of the practical function of the proposed system using precision, recall, F1 score, specificity and balanced accuracy and based on 600 orders established high accuracy and positivity of results.

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