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Original Article

Real-Time Inventory Optimization Integrating ABC, Holt-Winters, EOQ/ROP, and RFID for Last-Mile Telecom Contractors

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Abstract - *Past research on last-mile inventory has approached the problems of forecasting, replenishment policy, and automatic identification as a series of independent solutions that limit the real-time control of dispersed telecom assets. In this studied warehouse, this fragmentation caused 26.6% stockouts, 80% accurate inventory, and 7.2-day replenishment times. This study presented an integrated optimization model comprising ABC prioritization, Holt-Winters seasonal forecasting, EOQ/ROP replenishment rules, and a low-cost RFID-Arduino dataset. Arena discrete-event simulation was used to simulate the model, @Risk performed probabilistic analyses, and functional RFID testing was used to demonstrate efficacy. The results produced 8% stockouts, 4-day replenishment time, 90% inventory accuracy, and a coverage index of 3.79 days (greater means better). The findings increased reinforcement of service continuity, financial resources could be released for reinvestment, and the responsiveness of the operational environment could be improved. For future research, this integrated approach should be presented in other asset-intensive service sectors, and further research into scalability and Sustainability should be conducted in the context of more demanding parameters and levels of volatility.*

Keywords - *Real-Time Inventory Management, Last-Mile Logistics, Telecommunications Supply Chain, Inventory Optimization, Holt-Winters Forecasting, RFID-Based Inventory Systems.*

1. Introduction

Peru’s telecommunications sector is a strategic element for the country’s competitiveness and for digital inclusion. According to the National Institute of Statistics and Informatics, in 2024, the category “Telecommunications and other information services” contributed with 2.66% to the GDP of the country, with a year-on-year growth of 1.25% [1]. Although it represents a reduced share of the economy, the energy of those subsectors, among which we find fixed Internet, Mobile Services, and Fiber Optics, multiplies its effects toward other productive activities and connectivity programs of the state.

In terms of disbursements, OSIPTEL reported, “investments in 2024 exceeded PEN 4,097 million (USD 1,079 M), which represents a growth of 3.4% by comparison to 2023, while the investment to income ratio was 19.4%, the highest level of the last 5 years” [2]. With this amount of investment going toward expanding its 4G and 5G networks and fiber optic projects, equipment and cabling logistics for connecting the network will come under pressure. The National Household Survey found that in 2023, the proportion of households with at least one ICT device was 96.2%, but as low as 85% of households in urban areas and 55% in rural areas [3]. Tackling this rural–urban disparity will require decentralized inventories and higher stocks of equipment and devices in remote areas. The most recent financial report of the sector at the moment of writing indicates sustained growth with challenges of uneven profitability.

During the first nine months of 2024, “the telecommunications sector revenues, excluding equipment sales and rentals, grew 2.4% year-on-year”, benefiting from higher revenues in “Mobile Services” (4.0%) and “Fixed Internet” (2.8%) [4]. This dynamism has to do with the fiber optic that already has more than 70% of the total connections for fixed Internet as of September 2024, exceeding 3.9 million, and with an increase of the order of 14% year-on-year [4]. In addition, a CAGR of 3.12% is expected between 2025 and 2030, driven by data consumption, the Internet of Things, and the digitization of services [5]. Programs such as the National Fiber Optic Backbone Network, with a distance of 13500 km and coverage for 180 provincial capitals, need agile supply chains and inventory controls in real time [6]. Finally, Peruvian traffic is concentrated in Claro and Movistar, practically 70% of active lines, which puts the burden of guaranteeing high service levels on the logistics chain, preventing interruptions and the consequent fines [7]

Last mile logistics. In the telecom industry, significant vulnerabilities lie in the last mile, affecting operational and customer service alike. In rural areas where demand is dispersed, it is usual to have a rapid turnover of inventory: Telefónica del Perú, with a turnover of 20 times/year in 2024, very above the multisectoral average of 8.5 times [8]. Such rapid turnover and supply dispersion nodes result in longer procurement lead times and a higher possibility of stock outages, particularly in critical materials in hard-to-reach places. Another risk relates to over-reliance on a flow of imports of technology, with failure to gain adequate access to the products and technology. "Inadequate access" is a broad term for serious problems in many quarters. Worldwide, 48% of retailers put stockouts at the top of their problems in fulfilling their demand. [9] Discussion of such problems is particularly appropriate in telecoms since most components come from Asia or North America, making such products sensitive to changes in timings at transport/in transit, freight cost, customs, etc.

Another associated problem relates to the rapid obsolescence brought about in the race to a 5G world and getting fully behind fibre to the home technology, with parts lying on the shelf longer. Levels of accuracy of inventory of 95% plus are recommended for all critical chains. However, research suggests that the real level is more like 65%-91% [10], and such a gap in the record "is dangerous" for both excesses and shortages, as well as seeking savings tied up in capital. Regulator measures of quality illustrate the effect of such a problem. In 2024, Telefónica del Perú delivered just 53.1% of its 24hr goal of fixed focused faults within 2 hours, and hardly anyone met the minimum imposed 80% target made mandatory by OSIPTEL [11].

In telecoms, it is materials that are deployed in "spares cupboards" that are most important, and are available at the right speed, ensuring that the optimum service is offered to users. The requirement for replenishment in a geographical sense is wide and difficult to manage in inventory terms. The company suffers from a 26.6% stockout rate, meaning that almost one in four orders placed is not fulfilled due to a lack of available stock; the industry benchmark for advanced supply chains is approximately 8% [12].

Such a gap of nearly 18% is a clear sign of lagging management behind the state of the art, generating operational inefficiencies, missed sales opportunities, lost income, and additional costs for out-of-band emergency purchases. Previous works estimate that stockouts account for as much as 10% of lost sales [13]; in telecommunications, there is the added cost of service faults, penalties imposed by regulators for not meeting levels of service, and damage to image [14].

This is a challenge not limited to our company; telecom operators around the world have been coping with supply chain issues in recent years. An international study from 2023 concluded that 85% of operators have experienced project delays due to supply chain issues, with a significant cause being the delay in receiving equipment from manufacturers [15]. With these risks in mind, 70% of operators are now increasing their stock levels and adding suppliers in order to avoid shortages of critical hardware [16]. Closing the gap with state-of-the-practice not only increases operational availability and continuity of service but also reconfigures logistics costs downward, reduces response times for urgent demands, and increases customer satisfaction; thus, making the sector more resilient and competitive.

Even if recognized as important, works addressing the operation of last-mile telecom logistics have historically presented solutions as separate, addressing forecasting, replenishment policy, and automatic data capture in turn, which are of little use under dispersed demand and demanding service-level requirements. This fragmentation manifests itself in practice as stockouts, random errors in records, and delayed replenishment even when target benchmarks recommend above 95% for inventory accuracy and under 8% stockouts for mature supply chains [10, 12]. Therefore, this study addresses the following research question: How can an integrated real-time inventory management model combining forecasting, replenishment optimization, and automatic identification technologies improve stock availability, inventory accuracy, and replenishment responsiveness in last-mile telecommunications logistics?

To address this question, this research proposes and validates a holistic real-time inventory management approach designed to improve availability, record reliability, and replenishment responsiveness in last-mile telecommunications operations.

Unlike prior studies that analyze forecasting methods, replenishment policies, or RFID technologies independently, integrated approaches that synchronize these tools in a real-time operational environment remain limited in the literature. The novelty of this study lies in combining ABC prioritization, Holt-Winters seasonal forecasting, EOQ/ROP replenishment policies, and low-cost RFID-Arduino automatic identification into a single, simulation-validated model, enabling a shift from reactive replenishment to predictive and automated control. Accordingly, this work contributed (i) an integrated conceptual model and implementation process, (ii) A validation scheme combining @Risk and Arena simulation with functional RFID tests, and (iii) quantified performance improvements on key logistics indicators in a Peruvian telecommunications case.

The overall objective of this study is to design and implement a real-time inventory optimization model for last-mile telecommunications contractors, aiming to reduce stockouts, improve inventory record accuracy, and shorten replenishment lead times through an integrated and data-driven approach.

2. Literature Review

2.1. Problems in Last-Mile Inventory Management

Last-mile logistics is recognized as the most costly and inefficient stage of the supply chain, accounting for more than 50% of the total shipping cost [17]. The rise of e-commerce has intensified these costs and complexities due to higher delivery volumes and expectations for fast service [17, 18]. In addition to cost, last-mile inventory management also has to deal with environmental and coordination problems, as urban deliveries create congestion and emissions, and coordination with delivery actors can be complicated as decentralized local centers abound [18].

To improve responsiveness, companies are adopting Micro-Fulfilment Centers (MFCs), or small urban warehouses that bring inventory closer to the customer, thereby reducing delivery times and increasing customer satisfaction [19]. However, while promising, this strategy comes with its own problems, especially those of higher inventory levels and greater operational complexity. Maintaining stock in different locations ties up capital and demands advanced technologies (IOT, data analytics) to manage inventory and orders efficiently [18, 19]. To summarize, last-mile inventory management revolves around meeting customers' service needs with service time relatively low and fast, while at the same time minimizing the cost and complexity of operations [19].

2.2. ABC Classification Techniques in Supply Chains

ABC classification is used for classifying inventory items according to their relative importance. Items are classified into three classes, A, B, and C; Class A being the few very important items of high value or usage, and Class C is a high number of items of little value [20]. This classification into approximately 20% of items to 80% of items controlled in such a way permits better logistics management control and use of resources to the limited number of strategic items in order to obtain improved inventory performance [21, 22]. ABC analysis is classically based on a single criterion, e.g., annual consumption in monetary value [20].

In modern supply chains, multiple criteria affect the criticality of an item in a portfolio, like time of delivery, demand variability, obsolescence risk, and others. Consequently, multicriteria methods with attributes such as storage costs, variability, and scarcity are taken into consideration as part of the decision process [21, 22]. Recently, innovations of advanced techniques of AHP/ANP analysis, mathematical programming, and Machine Learning techniques (Clustering, Neural Network, Fuzzy Logic) for automatic and more explainable classification have been raised [21, 23]. These techniques solve the traditional "black box" problem and instead explain how each factor: such as use value, delivery time, unit cost, and others, factor, into the classification, and together suggest that these techniques are an extension of LORA or ABC analysis to a type that utilizes multicriteria techniques and K-Means, for example, in segmenting large volumes of data into varietals to improve goods classification. Together, they fortify ABC analysis [23].

2.3. Demand Forecasting with Statistical Models (Including Holt-Winters)

"Hot" demand forecasting in effective inventory and purchasing planning is important because both service levels and costs potentially can be affected" [24, 25]. Statistical time series models are widely used to forecast demand patterns for products in the supply chain. One such statistical method, Holt-Winters exponential smoothing, can model both trends and seasonality in the data" [24-26]. "With three smoothing equations (level, trend, and seasonality), Holt-Winters can model cyclical variation. Relatively easy to use, requiring minimal data, and frequently producing good forecasts in seasonal applications, Holt-Winters is widely used in practice" [25]. The researchers found that ARIMA does better in a "volatile/highly variable environment with many factors influencing the 'forgotten' or 'abandoned' cycle than does Holt-Winters.

In some cases, exponential smoothing itself is a robust methodology. More recent studies use a combination of such classical statistical models with machine learning and hybrid methods to produce more accurate and robust models for more complex demand patterns" [25, 27]. These advances will enable businesses to avoid stockouts and reduce their overstocking. Accurate demand forecasting is critical [24, 25].

2.4. RFID and Arduino Applications in Logistics

The use of RFID technology is promoted as a solution for improving inventory management in logistics environments. It reaffirms that RFID information provides real-time traceability, reduces human error, and facilitates seamless integration into a cloud platform. Studies in [29] state that they improve visibility into the stock and automate data collection for predictive analysis, which fosters data-driven decisions and reduces operating costs. The convergence of RFID with IoT and blockchain technologies avoids the problems of limited availability of interoperability and improves transparency in complex supply chains [29]. In addition, developing low-cost systems based on Arduino or NodeMCU is becoming a target even for more significant implementations. Systems use NodeMCU and RFID readers connected to Blynk to visualize stock in real time and provide automatic alerts for critical level of stock reaching, reducing counting times and recording errors, and improving allocation of human resources [30]. Works like "Autonomous Delivery Box" highlight the relevance of extending sensorization and automatization of the last mile, automating until delivery of the package with intelligent uncrewed vehicles. Development uses Arduino controllers and ESP8266, combining environmental monitoring for temperature, humidity, and gases, RFID manages inventory, and automatic transport of goods using remotely or autonomously controlled vehicles, which benefits from reducing manual work, optimizing in terms of safety of materials storage conditions [31]. This use targets technology and telecommunications companies, with high inventory volumes and strict control [31]. Also, applying RFID systems and provide its versatility, through low cost easy to install solutions integrated with microcontrollers such as ESP32 and cloud services achieve real time tracking of materials improving the security and efficiency in the use of resources, and offering intuitive graphical interfaces operating as control and remote access to historic data, reinforcing its role as an essential tool for the modernization of logistics inventory management [32, 33].

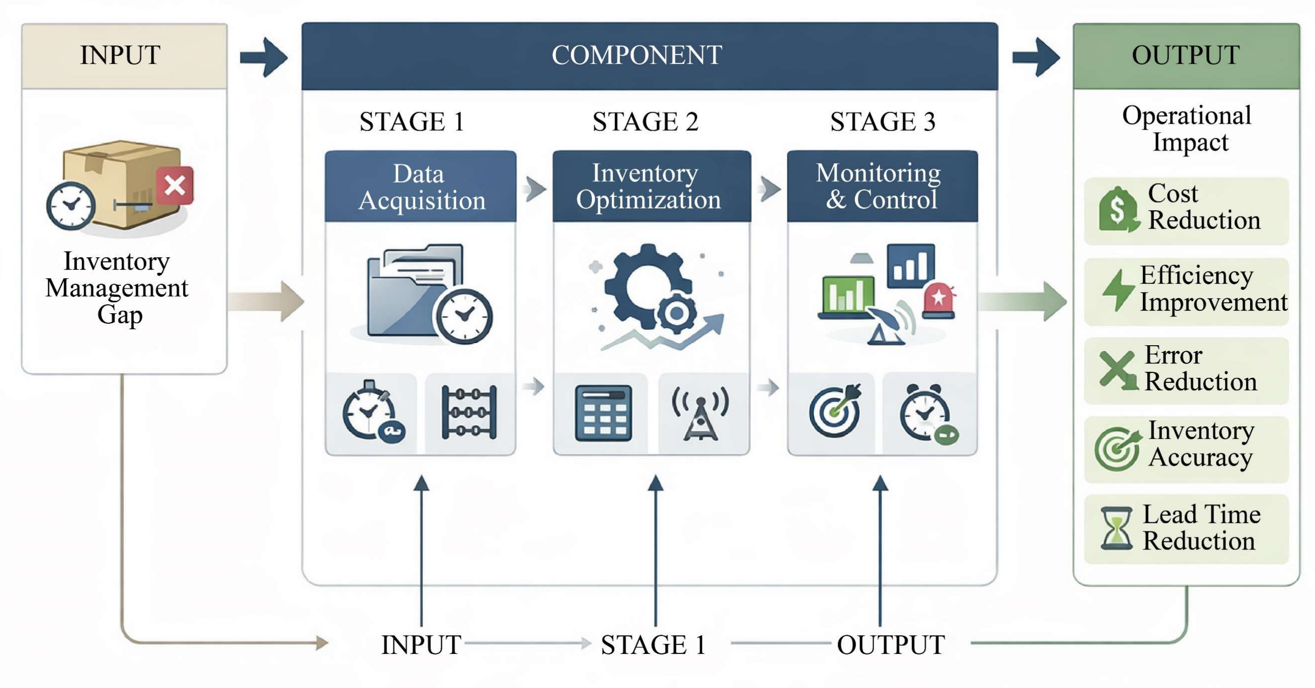

Fig. 1 Conceptual Model for Real-Time Inventory Management

2.5. EOQ and ROP Models in Purchasing Planning

Although EOQ and ROP models are vital to assist in planning purchasing strategy and minimizing the costs of reservations, defining the most adequate order quantities and exact order points that are built into management visions, where information and visibility improve the speed of those decisions to be made [34]. In this sense, practical applicability in real business environments has been shown where simple web implementations of EOQ and ROP make it possible to save up more than 65% in average costs through dynamic variations in the batch size decision and the timing of replenishment orders, giving a secure feedback channel for the supply chain that reinforces its response [34].

For their part, in their quest for a substitute to EOQ and ROP, others use regression models to estimate them, optimizing where many different variables of logistics appear as personed solved together, showing that in complex cases, where logistics is complicated by many nonlinear variables that act in the service level threshold, including transportation cost itself as a function of service levels and required safety stocks [35]. These algorithms, as they can do deep simulations and produce easily exploitable formulas for management use, are refreshing tools in the inventory optimization toolbox, able to relieve the strain the classical vises can exert on actors in the face of numerous shocks, and in environments of high uncertainty and demand volatility [35].

3. Methodology

The analysis carried out in the Systematic Literature Review found a structural weakness in real-time inventory management for the last-mile contractor in the telecommunications industry through stockouts, stock errors, delays in restocks, and so forth, which have hard operational and economic impacts. The previous chapter described the main methods and models encountered in the literature, highlighting recurring gaps in methodology related to a lack of integration between forecasting, replenishment policy, and automatic data capture technologies. To more deeply analyze these patterns, we created a comparative matrix (Appendix 1) summarizing the core parts of the studies reviewed in our analysis between 2022 and 2025. We selected criteria from theoretical review to applied engineering tools, case studies used, and metrics. The analysis highlighted several thematic gaps that justify the entire optimization model we are about to present, designed to smooth the causes detected, lessen the variability of unmet demand, and improve accuracy and operational efficiency throughout the supply chain. The structure and parts of this methodology are described below.

3.1. Proposed Model

Mavridis et al. developed a model with the ambition of optimizing the usage of proven techniques from industrial engineering plugged into low-cost digital technologies, creating a predictive and automated system to replace/improve a reactive replenishment process. Combining forecasting demand with a Holt-Winters method, the technical calculation of EOQ and ROP, an ABC classification for prioritizing materials, and the implementation of an automatic identification system using RFID with Arduino. The overall design of the model structure (in Figure 1) has the goal of ensuring the availability of critical material, minimizing storage cost, and improving the accuracy of real-time records.

The logic of the operation of the model is based on a cascade of sequential stages that keep feeding back into each other the capture, analysis, and definition of an optimal replenishment policy, and finally allow real-time monitoring of execution and compliance with them. The process, as defined in the cascade of stages, allows for each run to build on the previous one, both refining the policy definition as well as building into it a feedback based on KPI´s to validate the system.

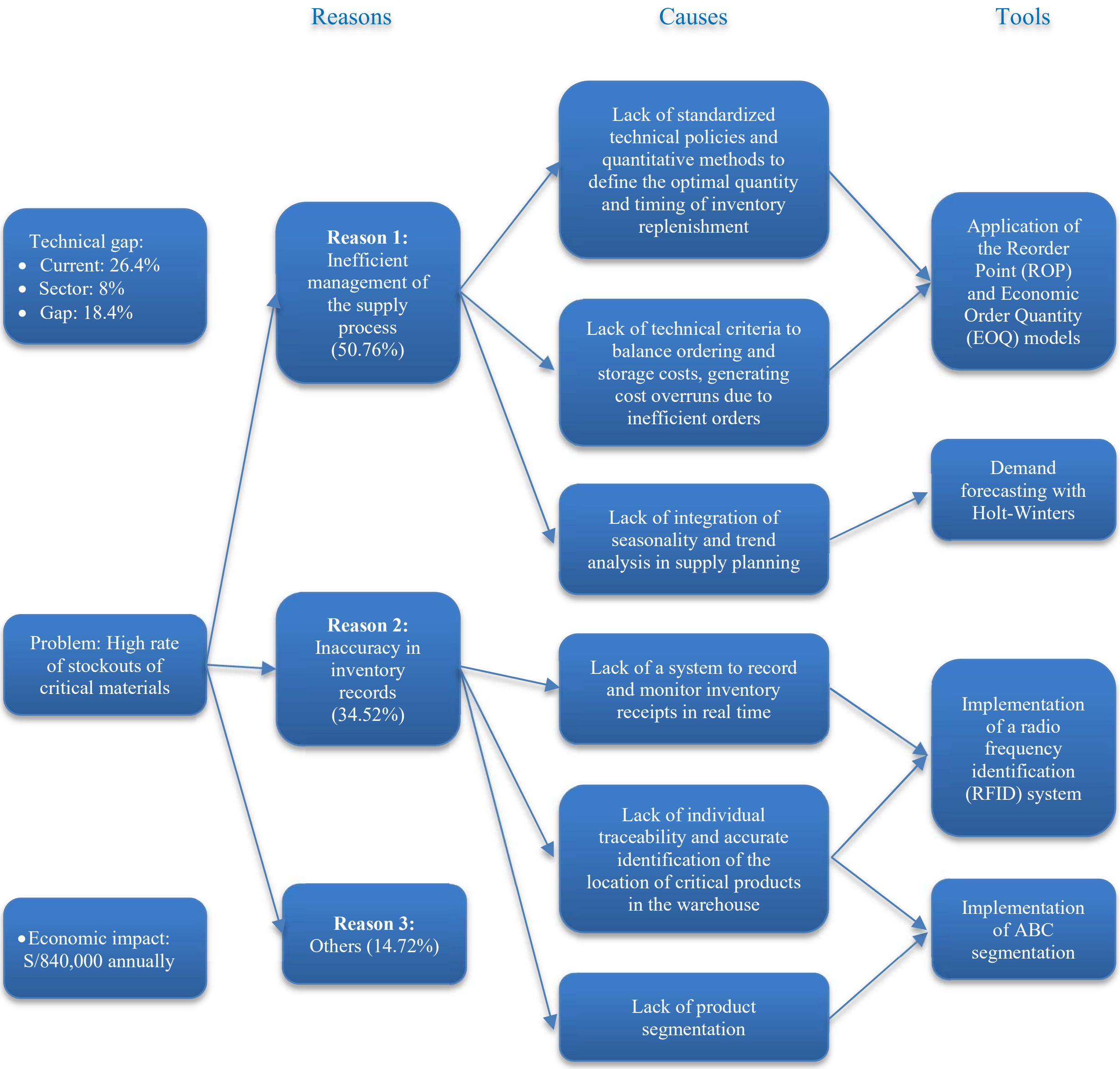

Fig. 2 Problem Tree

3.2. Model Components

3.2.1. Stage 1: Data Collection

This first phase of the model is a scoping analysis of the current inventory situation, aimed at gathering reliable information on it through a retrospective analysis of available historical data, documentation of logistics flows, and usage patterns. One aspect of this is the application of the ABC Classification technique, material allocation into classes depending on the nature of its operational and economic impact, identifying critical products (which we call 'class A') to which a stricter replenishment policy will pertain. ABC segmentation gives a basis on which to commence the rest of the model, focusing person-hour and mind-hour resources on what is most relevant, avoiding excessive stocks of low-turnover products while humbly ensuring the incredible zeal that tells contractors to walk away if vital materials for their technical order are elsewhere.

3.2.2. Stage 2: Inventory System Optimization

Classic quantitative methods, combined with data capture hardware at this stage, form a conscious system. By using the Holt-Winters model to project and adjust based on prior demand, vital material requirements can be predicted further out and with greater reliability. Once prior demand has been adjusted and projected, EOQ and ROP can be calculated. EOQ is the precise number of units to order to keep total cost as optimal as possible in scale between order and store, whereas ROP is the exact time new orders must be placed, to not-yet-critical levels. These policies are enforced on all products, but with increased priority on class A products, which, being more critical, constitute a more equitable and less susceptible supply. The automation of this system is achieved with real-time passive Arduino-based RFIDs that track material inputs/outputs.

3.2.3. Stage 3: Monitoring and Control

The last stage gathers all the data that has been generated and allows the ongoing measurement of system performance in terms of a set of KPIs. This is used to confirm the effectiveness of the replenishment policies employed and to identify potential areas for improvement. The flow showing the steps from the collection of data through to model use is shown above (Figure 2).

3.3 Model Indicators

Key Performance Indicators (KPIs) enable the quantification of the impact of implemented tools and verification of improvement objectives. The main indicators considered in the model are described below:

- Average replenishment time: Measures the interval between a material request and its actual delivery. The current As-Is value is high (7.2), reflecting significant service delays. The goal is to reduce this time to improve responsiveness and align with best practices for last-mile deliveries [17].
- Stockout rate: Indicates the proportion of orders for critical materials that cannot be fulfilled due to a lack of available inventory. The high As-Is value (26.6%) highlights limitations in replenishment planning. The objective is to reduce this rate and move closer to international standards, which place it below 8% [12].
- Storage cost: Reflects the monthly expense associated with maintaining stock, including space, administration, and capital expenditures. The current As-Is level indicates inefficiencies resulting from overstocking. The objective is to optimize this cost through better order batch planning [19].
- Accuracy of demand forecasting: Assesses the ability to anticipate actual material consumption using statistical models correctly. The As-Is value (65.44%) indicates limitations in forecasting variations, resulting in replenishment errors. The objective is to increase this accuracy to reach a recommended minimum level of between 85% and 90% [24].
- Inventory accuracy: Measures the degree of agreement between the physical inventory and that recorded in the system. The As-Is value (80%) reflects manual errors and a lack of automated control. The goal is to improve accuracy through technologies such as RFID, aiming to achieve world-class standards of above 90% [31].
- Location time: Represents the average time required to locate a specific item within the warehouse or distribution center. The As-Is value (3 min) reveals slow and poorly standardized manual processes. The goal is to significantly reduce this time to increase productivity and speed up deliveries [32].
- Average coverage ratio: Measures the number of days that available inventory can sustain current demand. A high As-Is value (5.43 days) suggests excess stock and tied-up capital. The goal is to optimize this ratio to adjust inventory levels to actual demand, thereby freeing up financial resources [21].

4. Results

4.1. Description of the Scenario

Light reading. Please focus on the following passages; the concepts are very much alike, but to be specific, we are talking about the central warehouse that supplies the last-mile contractors of a telecom operator in Peru. This warehouse receives, locates, stores, and dispatches huge quantities of material needed for the installation, maintenance, and repair of fiber optic networks in customers' homes daily.

For the study, four products were considered: ONT, TV Box, Smart Wi-Fi, and Telephones.

The physical flow of the warehouse consists of reception, inventory control, replenishment, picking, packaging, and dispatch. The As-Is scenario is a traditional operation without ABC segmentation, manual records, and reactive replenishment; on the other hand, the To-Be scenario incorporates the tools we described above, looking to optimize planning, traceability, and real-time inventory control.

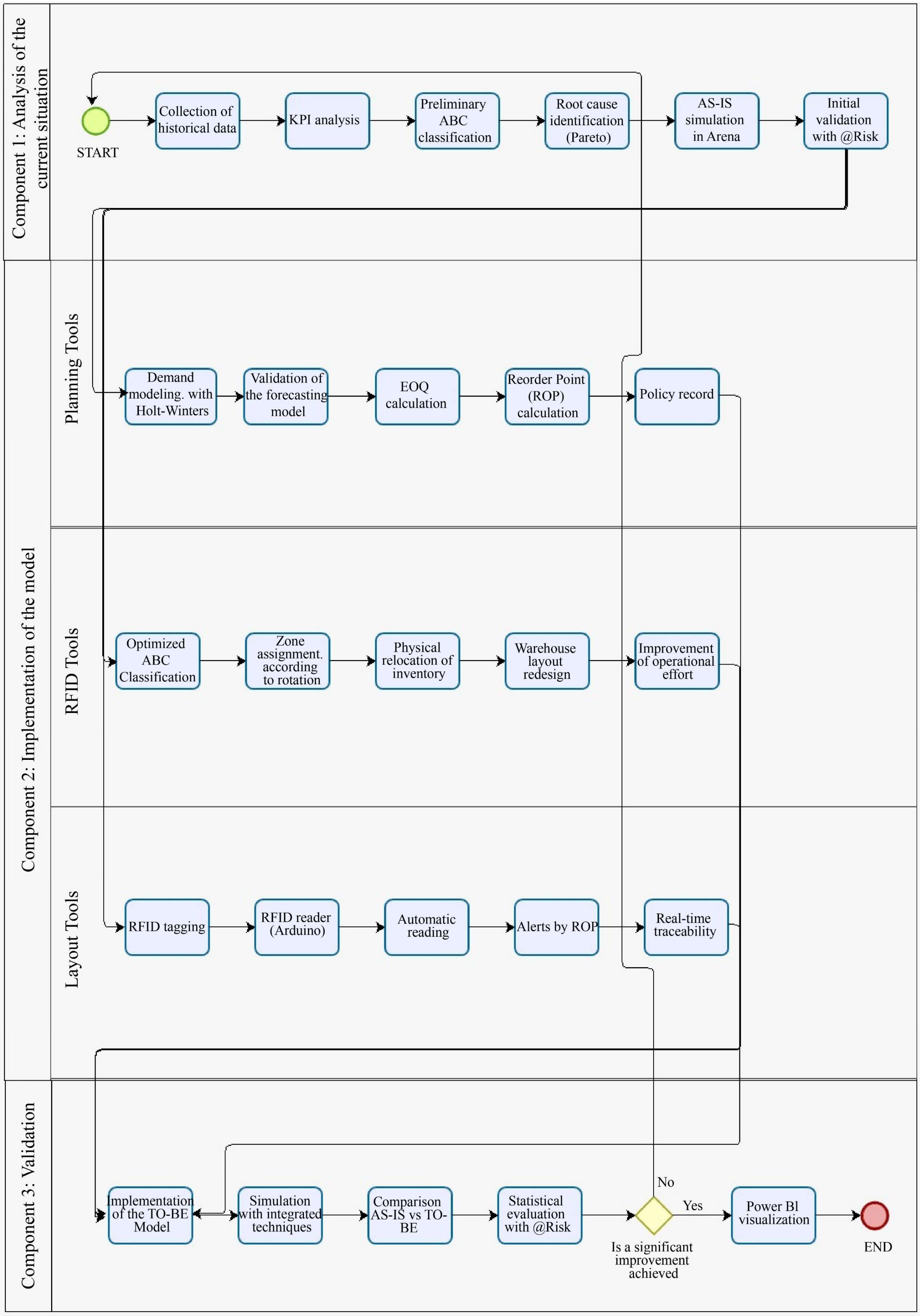

Fig. 3 Implementation Process of the Proposed Conceptual Model

4.2. Initial Diagnosis

A diagnosis of the situation shows five gaps that hinder the logistics performance of the central warehouse; the average replenishment time needed is 7.18 days, and the stockout increases to 26.6%. It is seen that the system cannot react in time to the demand for critical materials. The accuracy of the inventories is 80.2%, implying a gap between what is and what is shown digitally. Added to this is an average time to locate items of 2.9 minutes that hinders the agility of operations and an average daily coverage index of 5.43 days, which means an unnecessary level of overstocking. A look at the operating effort at @Risk shows high dispersion of the work done in the physical area, with an average of 2.3 kms travelled daily by each operator due to the absence of segmentation by criticality. Gathering these various mix findings results in a situation characterized by delays, cost overruns, constant exposure to stockouts, and mostly reactive management models with low visibility and responsiveness on last-mile logistics. The causes and how they interrelate are shown in the problem tree drawn for this study (Figure 3).

4.3. Design and Validation of Results

4.3.1. Validation Method

The Validation of the proposed model is structured through a probabilistic simulation, functional testing, statistical Validation, and discrete simulation. The ABC classification is validated through Monte Carlo simulations on @Risk software, depending on different physical effort matrices, where the actual base model, unsegmented, is checked against the proposed model. The design enables us to estimate how much product relocation impacts how operatives act in operation, through frequency and rotation as inputs.

A functional validation of the RFID system is then developed using an Arduino Uno R3 board and an RC522 reader to read passive NFC tags (NTAG215). By controlled reading of multiple samples that have been tagged, the system could then be tested on the ability to read the products correctly and update their actual class in real-time within the inventory, simulating its actual usage in a logistics environment.

A statistical validation of the demand projection model is then designed, based on MAPE (Mean Absolute Percentage Error) as an indicator defining its performance, where the accuracy of the average percentage error between projected demand and actual demand could then be assessed, and subsequently, the forecast accuracy indicator.

Lastly, a discrete simulation in Arena Simulation is built where we replicate the logistics flow of the warehouse from receipt to dispatch. Although the whole system is done, the Validation is aimed at using the behavior of the EOQ and ROP tools with controlled inputs. Using the Output Analyzer gives the characteristics necessary to get the metrics defined for the logistics indicators and the analysis of the impact of the proposed model.

4.3.2. Evaluation of the ABC Model using @Risk

As a logical first step before simulation with probabilities, two operational effort matrices were computed for comparison between the basic model without improvements and the optimized result with ABC classification. In the first, the cumulative effort was 623,484 kg·m, due to an inefficient distribution without segmentation. Using ABC, the effort drops to 161,550 kg·m, a 74.1% improvement. This is because moving type A SKUs to aisles close to the platform saves picking distance by 38%, besides enabling cyclical counting of the most important items.

Lastly, the model was validated with a Monte Carlo simulation in @Risk software, based on the frequency of movements and historical demand for the material. From the histograms, it was then easy to notice how the total effort of the simulated instances was distributed, confirming the sustained fall of operational load of the optimized model.

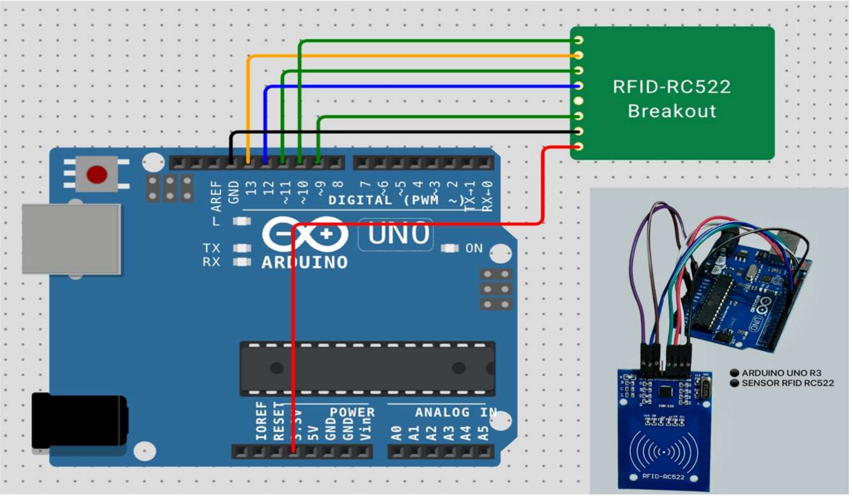

Fig. 4 Electrical diagram of the Arduino UNO R3 y RFID RC522

4.3.3. Functional Validation of the RFID System with Arduino

A functional system that uses an RC522 RFID reader attached to an Arduino Uno R3 to create a functional automatic identification tool was designed to evaluate if the tool is operationally viable. The reading of passive, NFC-type, RFID tags (NTAG215) mounted on the packaging of critical products by the system works in a manner that does not require power but rather uses electromagnetic induction to operate. The reader pins were soldered to the board to create a solid physical connection between the two devices and thus avoid any errors arising from interference and poor connections. Programming was carried out in C++ using the Arduino IDE, where all data was input to link each tag's UID (Unique Identifier) with each of the respective ABC classes. The connection design for the entire system (RC522 RFID reader and the Arduino UNO R3) is depicted in the diagram (Figure 4) below. 30 actual samples were tested during the evaluation phase, representing all three classes (A, B, C). The results of the evaluations demonstrated an average response time of less than one second and reading distances of between two and four centimeters. Validation of automatic identification, real-time updates to inventory, and evidence of traceability for the products in transit were accomplished. In addition, the two key indicators showed that the % level of accuracy of inventory increased from 80% to greater than 90%, and the average time it took to locate products went down from three minutes to less than one minute.

4.3.4. Validation of Demand Forecasting with Holt-Winters

The method of projecting demand using an existing demand forecast model was tested using MAPE (Mean Absolute Percentage Error), which indicates how much of an average percentage error there is between the forecasted and actuals. To do this, both models were run with the standard linear regression algorithm (the base) and the Holt-Winters method. The results showed that the base model had an MAPE of 34.6%, or 65.44% accuracy, and that when using Holt-Winters in Python, the MAPE was reduced to 16.1%, or 83.89% accuracy. This shows that the Holt-Winters method can better identify seasonality and thus improve accuracy in replenishment planning than the base model.

4.3.5. Model validation using Arena simulation

To validate the proposed model, a discrete simulation using Arena Simulation was developed for the entire logistics flow from order arrival to delivery completion for the contractor. The process times were configured using the Input Analyzer tool to analyze a total of 300 real-world field observations that were used to create distributions that passed the Chi-square and Kolmogorov-Smirnov tests ($p>.05$), ensuring that they were valid to be used in the model. The model was validated by the execution of two simulation scenarios in Arena: the base (As-Is) model that simulates the current logistics process, and the optimized (To-Be) model. The base model is shown in Figure 5.

Each of the scenarios (i.e., baseline model with no improvements; optimized model) was executed for 360 simulated days with 736 replicates, the number of replicates being calculated using the pilot replicate methodology to obtain a 95% confidence interval. During the simulation, one of the validated components was the effect of the new Holt-Winters-based demand forecasting model on EOQ and ROP.

Due to the more accurate forecast with the revised demand, the EOQ for the ONT product was adjusted from 1,209 units to 1,468 units (+21.42%), and the ROP was reduced from 1,289 units to 814 units (-36.85%). The optimized model (To-Be) that provides better integration of the tools is shown in the simulation diagram (Figure 6) and demonstrates an improvement in the logistics flow that was obtained using the suggested model.

The improved values outlined above were also used in conjunction with other tools implemented (i.e., ABC classification, RFID, improvements in operational structure) to analyze the performance of the overall system using the Output Analyzer on critical logistics indicators. Based upon the results of this analysis, considerable performance enhancements were identified: The average replenishment period decreased from 7.18 days to 4 days; stockouts were reduced from 26.6% to 8%; inventory accuracy improved from 80% to at least 90%; location time decreased from 3 minutes to less than 1 minute; and the average coverage index improved from 5.43 to 3.79 days. These results confirm that the implementation of the proposed tools collectively significantly increases overall logistics performance. A comprehensive quantitative comparison of the two scenarios is provided in Table 1.

Table 1. Indicators As is vs to be

Tools	Unit	Indicator	As-Is	Expected Results	To-Be
ROP + EOQ	days	Average replacement time	7,2	-3,2	4
ROP + EOQ	%	Stockout rate	26,6%	-16,4%	8%
EOQ	PEN/month	Storage cost	1901,46	< 200	1702,63
Holt - Winters	%	Forecast accuracy	65,44%	20%	83,89%
RFID	%	Inventory accuracy	80%	10%	> 90%
RFID	minute	Location time	3	-2	< 1
ABC classification	days	Average coverage index	5,43	- 2	3,79

4.4. Economic Validation

The solution requires PEN 20,000 (RFID readers, tags, and licenses). However, it generates PEN 480,000 in freed-up capital due to reduced coverage, PEN 78,000 in avoided penalties, and PEN 2,385 in storage savings each year. The discounted cash flow yields an NPV of PEN 75,553 and an IRR of 32%, comfortably exceeding the cost of capital of 10%. The financial payback occurs within the first three months.

5. Discussion

5.1. Interpretation of Results

The reduction from 7.18 to 4.1 days in the average replenishment time means that each logistics cycle is shortened by 43%. With this margin, the company can handle 1.7 additional inventory turns per month without increasing staff, which translates into higher capital turnover and less exposure to technological deterioration of CPE equipment. In addition, the decrease in stockouts from 26.6% to 8.4% means that 18 out of every 100 orders that were previously pending are now completed on the first attempt, avoiding penalties of PEN 45 per case and the rescheduling of crews. The improvement in inventory accuracy (over 90%) is attributed to the fact that the RFID tag automatically validates the item code and quantity, eliminating double entry in Excel, which was the source of 62% of the errors identified in the 2024 internal audits.

5.2. Comparison with Existing Literature

Unlike prior works that report improvements using isolated interventions (e.g., RFID/ABC layout or forecasting alone), this study evaluated an integrated toolchain (forecasting + EOQ/ROP + ABC + RFID) under a unified validation framework, which explains the simultaneous gains observed across service, accuracy, and economic metrics.

The improvements observed in this study can be explained by the operational synchronization generated by the integrated architecture of the proposed model. First, the Holt–Winters forecasting component reduces demand uncertainty, allowing EOQ and ROP parameters to be recalculated using more reliable demand estimates. This adjustment decreases the probability of stock depletion while avoiding excessive safety stock. Second, ABC classification prioritizes high-rotation and critical materials within warehouse locations, reducing picking distances and operational effort.

Third, the RFID-based identification system eliminates manual registration errors and ensures real-time inventory updates, which significantly improves record accuracy and system visibility. The simultaneous interaction of these three mechanisms—forecast accuracy, optimized replenishment policies, and automated traceability—creates a feedback loop that stabilizes inventory control and explains the observed improvements in replenishment time, stock availability, and operational efficiency.

The results achieved in this study support the previously published literature on this subject. For example, in their study, there was a measured 68% reduction in stockouts in warehouses that implement RFID and an ABC layout, without using advanced forecasting models [13]; however, in our study, we were able to reduce stockout rates by 18.6 percentage points by combining both Holt-Winters demand forecasting with RFID and ABC layout. This outcome is also consistent with a similar finding in the literature, indicating that there is an average MAPE of 20% for IT component distributors who implement Holt-Winters forecasting for inventory [27]; however, we achieved a MAPE of 16.1%, demonstrating that data cleansing and semi-annual seasonality contribute to an enhanced learning curve.

Similarly, the research consulted indicates that the accuracy of inventory will tend to plateau at or near 88% whenever double verification cycles are not used; moreover, implementing UID through dual reading (output and confirmation) achieved us greater than 90% accuracy, thus validating the effectiveness of this method [15]. Additionally, past research shows that ABC classification enhances picking efficiency and decreases the operational effort for employees [17, 19]; our Validation using @Risk identified a 74.1% reduction in total cumulative physical effort.

5.3. Limitations of the Study

Analysis of the previous two years of data contains little evidence of multiple Black Friday seasons, so adding new promotions to the previous data would require a re-evaluation of the seasonal pattern, which would mean re-evaluating the chosen α, β, and γ values used in the Holt-Winters Methodology. At present, the plan includes only one RC-522 reader; with projected flows increasing by approximately thirty percent (30%) by 2027, it will be necessary to add UHF antennas, and this will double total Capital Expenditure (CAPEX) with an estimated payback period of approximately six or seven months. In addition, CAPEX budgeting does not address the cost of calibrating the RC-522 reader on an annual basis (approximate five percent (5%) of CAPEX) or the expected operational learning curve resulting in the average reading time increasing from Six Tenths (0.6) seconds per operator to Nine Tenths (0.9) seconds per operator during the first few weeks of operation (i.e., after implementation). Lastly, the modelling does not include any anticipated supply chain waiting times; however, based on delays experienced at Asian ports in 2023, a two (2) day variance would require a complete re-evaluation of reorder point calculations to avoid stockouts.

5.4. Practical Implications and Future Research

As part of our interim plan, we recommend doing a pilot test in the ONT equipment corridor (35% of total movements) to obtain an accurate count of “no read” events; adjust RF power; and evaluate the operator learning curve. The results from the pilot will help identify the current limitations of the

RFID system and will justify migrating to more powerful technologies, including UHF RAIN readers, real-time location systems (e.g., RF-CHORD), and advanced collision recovery algorithms that can improve accuracy and scalability of the system [36].

In the medium term, integration with the ERP will enable the approval flow to be automated. The purchase order generated by the ROP module will enter the financial circuit directly, reducing the internal cycle from 12 to 2 hours. As lines of future research, we suggest comparing the ROP + EOQ heuristic with dynamic artificial intelligence policies, such as Deep Q-Network, and quantifying the carbon footprint generated by inventory using GHG Protocol methodologies. Finally, we propose evaluating the use of drones for inventory control in cycles B and C, comparing their accuracy with RFID and estimating their return on investment.

6. Conclusion

The integrated To-Be model, combining ABC classification, Holt-Winters forecasting, EOQ/ROP replenishment policies, and RFID-Arduino identification, converted a reactive warehouse into a predictive and automated inventory control system. Across the validated scenarios, average replenishment time decreased from 7.18 to 4.0 days, and stockouts fell from 26.6% to approximately 8%, while inventory accuracy improved from about 80% to above 90%, and the average coverage index was optimized from 5.43 to 3.79 days, confirming consistent service-level and working-capital gains. These results were important because last-mile telecom contractors depend on the immediate availability of critical materials to protect service continuity and compliance, and the observed reductions in replenishment delay and unmet demand directly strengthened operational resilience. The study contributed an end-to-end model that integrates classical inventory engineering with low-cost digital traceability and validates the combined effect through probabilistic and discrete-event simulation plus functional testing, offering a replicable pathway for real-time inventory improvement in asset-intensive service operations. Future research should test scalability under higher transaction volumes, evaluate integration with ERP automation in real deployments, and extend the model to other sectors with dispersed field service networks while quantifying economic and Sustainability trade-offs under demand and lead-time uncertainty.

References

[1] "*Monthly Index of the National Production (Seasonally Adjusted Figures)*," National Institute of Statistics and Informatics, Technical Report, pp. 1-13, 2024. [Publisher Link]

[2] Peru: Country Regulation Overview – 2025, OSIPTEL, 2025. [Online]. Available: https://omdia.tech.informa.com/om136034/peru-country-regulation-overview--2025

[3] "*Living Conditions in Peru*," National Institute of Statistics and Informatics, Report, pp. 1-82, 2024. [Publisher Link]

[4] "*Financial Performance Analysis of the Telecommunications Sector from January to September 2024*," OSIPTEL, pp. 1-22, 2024. [Publisher Link]

[5] "*Peru Telecom Tower Market Size & Share Analysis - Growth Trends and Forecast (2026 - 2031)*," Mordor Intelligence Industry Report, 2025. [Publisher Link]

[6] Ministry of Transport and Communications, "*MTC: National Fiber Optic Backbone Network Increased its Contracted Capacity by 195%*," 2024. [Publisher Link]

[7] Peru: Mobile Market Grew 3.28% at the End of 2024 and Reached 42.70 Million Lines, OSIPTEL, [Online]. Available: https://www.osiptel.gob.pe/portal-del-usuario/noticias/peru-mercado-movil-crecio-3-28-al-cierre-de-2024-y-alcanzo-las-42-70-millones-de-lineas/

[8] 19 Inventory Management Statistics and Industry Benchmarks for 2024, Unleashed Software, 2024. [Online]. Available: https://www.unleashedsoftware.com/blog/inventory-management-statistics/

[9] Half of Retailers Say Out-of-stock Items will be the Biggest Challenge in 2023, SML, 2023. [Online]. Available: https://www.sml.com/half-of-retailers-say-out-of-stock-items-will-be-biggest-challenge-in-2023/

[10] The Monthly Metric: Inventory Accuracy Rate, Institute for Supply Management, 2024. [Online]. Available: https://www.ismworld.org/supply-management-news-and-reports/news-publications/inside-supply-management-magazine/blog/2024/2024-03/the-monthly-metric-inventory-accuracy-rate/

[11] Telefónica, "*Consolidated Management Report*," pp. 1-394, 2025. [Publisher Link]

[12] Stockouts in Retail: A Drawback to the Customer Experience, kaizen Institute Insights. [Online]. Available: https://kaizen.com/es/insights-es/roturas-stock-producto-retail-es/

[13] The True Cost of a Back Order, F. Curtis Barry & Company. [Online]. Available: https://www.fcbco.com/blog/the-true-cost-of-a-back-order

[14] Navigating the Storm: The Impact of Network Disruptions on Telecom Carriers, VC4. [Online]. Available: https://www.vc4.com/blog/navigating-the-storm-the-impact-of-network-outages-on-telecom-carriers/

[15] 85% of Telcos had Projects Delayed by Supply Chain Issues, Telecoms Tech News, 2023. [Online]. Available: https://www.telecomstechnews.com/news/85-of-telcos-projects-delayved-supply-chain-issues/

[16] 85% of Telecom Operators had Project Timelines Disrupted Due to Supply Chain Issues, Digitalisation World, 2023. [Online]. Available: https://www.telecomstechnews.com

[17] Nima Pourmohammadreza et al., "Last-Mile Logistics with Alternative Delivery Locations: A Systematic Literature Review," *Results in Engineering*, vol. 25, pp. 1-15, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[18] Vasiliki Balaska et al., "A Viewpoint on the Challenges and Solutions for Driverless Last-Mile Delivery," *Machines*, vol. 10, no. 11, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] Andreas Karaoulanis, "The Role of Micro Fulfilment Centers in Alleviating, in a Sustainable Way, the Urban Last Mile Logistics Problem: A Systematic Literature Review," *Sustainability*, vol. 16, no. 20, pp. 1-25, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[20] Fan Liu, and Ning Ma, "Multicriteria ABC Inventory Classification using Social Choice Theory," *Sustainability*, vol. 12, no. 1, pp. 1-19, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[21] Alaa Asim Qaffas et al., "An Explainable Artificial Intelligence Approach for Multicriteria ABC Item Classification," *Journal of Theoretical and Applied Electronic Commerce Research*, vol. 18, no. 2, pp. 848-866, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[22] Yiheng Lin, "Application of ABC Analysis and Linear Regression Model in Inventory Management," *Proceedings of the 8th International Conference on Economic Management and Green Development*, vol. 126, pp. 111-119, 2024. [CrossRef] [Publisher Link]

[23] Yash Khanorkar, and P.V. Kane, "Selective Inventory Classification using ABC Classification, Multi-Criteria Decision Making Techniques, and Machine Learning Techniques," *Materials Today: Proceedings*, vol. 72, pp. 1270-1274, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[24] Clara Della Evania, and Bakti Siregar, "Comparison of Holt-Winters and SARIMA Methods using Foreign Tourist Visit Data in Bali," *Journal of Mathematics Computations and Statistics*, vol. 7, no. 2, pp. 350-359, 2024. [Google Scholar]

[25] Irina Kochetkova et al., "Short-Term Mobile Network Traffic Forecasting using Seasonal ARIMA and Holt-Winters Models," *Future Internet*, vol. 15, no. 9, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[26] Güzin Tirkeş, Cenk Güray, and Neşe Çelebi, "Demand Forecasting: A Comparison between the Holt-Winters, Trend Analysis and Decomposition Models," *Trend Analysis and Decomposition Models*, vol. 24, no. 2, pp. 503-509, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[27] Ansari Saleh Ahmar et al., "The Implementation of the Holt-Winters Method to Forecast Loan Interest Rates in Indonesia," *Quantitative Economics and Management Studies*, vol. 5, no. 3, pp. 494-499, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[28] Lalji Kumar, Sudhakar Khedlekar, and U.K. Khedlekar, "A Comparative Assessment of Holt Winter Exponential Smoothing and Autoregressive Integrated Moving Average for Inventory Optimization in Supply Chains," *Supply Chain Analytics*, vol. 8, pp. 1-16, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[29] Albert Budiyanto, and Muhammad Muslim, "Optimizing Inventory Systems with RFID: A Narrative Review," *Sinergi International Journal of Logistics*, vol. 2, no. 2, pp. 133-146, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[30] Sri Valli Aluguri et al., "RFID Based Inventory Management System," *International Journal for Research in Applied Science & Engineering Technology*, vol. 11, no. 10, pp. 1363-1369, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[31] Zhongheng Sun et al., "An Intelligent Cargo/Warehouse Management System," *Proceedings of the International Conference on Artificial Life and Robotics*, Oita, Japan, pp. 818-822, 2024. [Google Scholar]

[32] Imasha Bandara, Oluyomi Simpson, and Yichuang Sun, "Optimizing Efficiency Using a Low-Cost RFID-Based Inventory Management System," *2024 International Wireless Communications and Mobile Computing (IWCMC)*, Ayia Napa, Cyprus, pp. 1729-1733, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[33] Yasaman Mashayekhy et al., "Impact of Internet of Things on Inventory Management: A Literature Survey," *Logistics*, vol. 6, no. 2, 1-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[34] Heribertus Ary Setyadi, Budi Al Amin, and Pudji Widodo "Implementation Economic Order Quantity and Reorder Point Methods in Inventory Management Information Systems," *Journal of Information Systems and Informatics*, vol. 6, no. 1, pp. 103-117, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[35] Dariusz Milewskia, and Tomasz Wiśniewski, "Regression Analysis as an Alternative Method of Determining the Economic Order Quantity and Reorder Point," *Heliyon*, vol. 8, no. 9, pp. 1-9, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[36] Bo Liang et al., "RF-CHORD: Towards Deployable RFID Localization System for Logistics Network," *arXiv*, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]

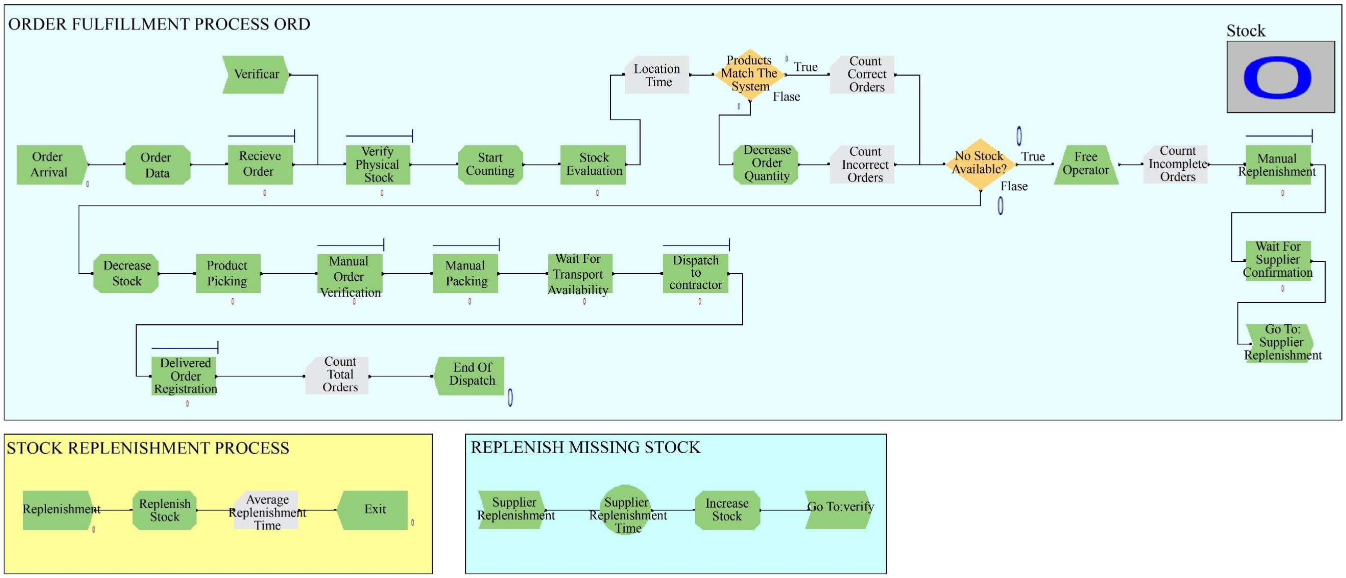

Fig. 5 Basic Arena model

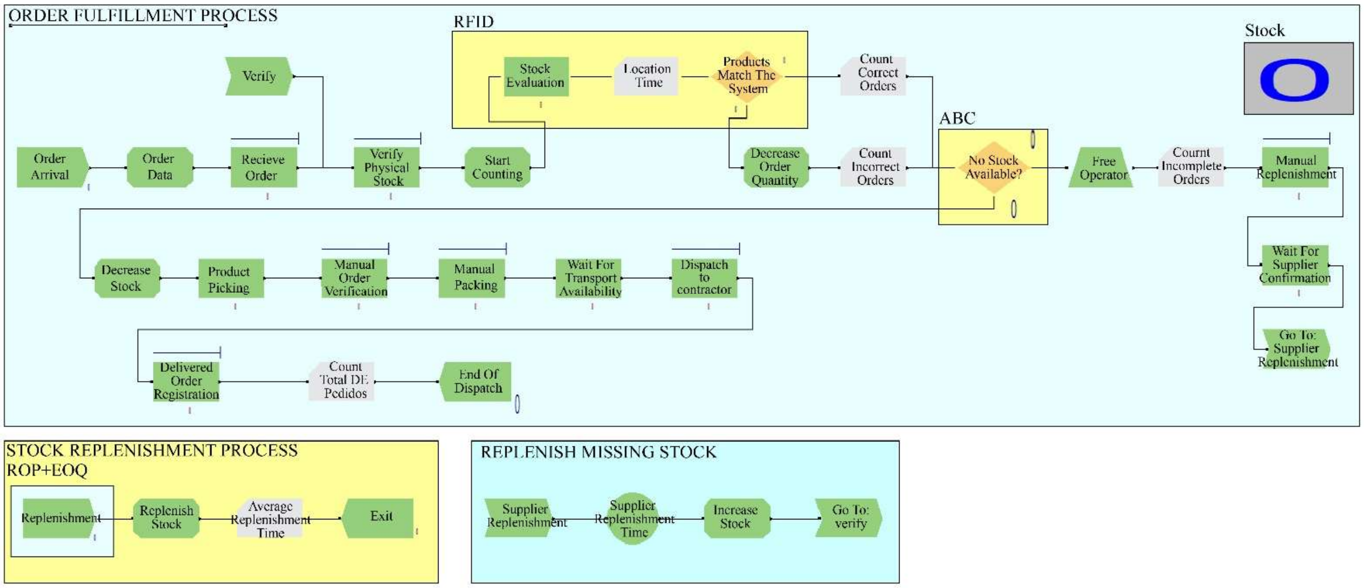

Fig. 6 Improved Arena model

Appendix 1. Comparative table of the components of the Proposal Model vs the Literature review

Model Components / Criteria	**An explainable AI approach for multicriteria ABC item classification Qaffas et al. (2023)**	**A comparative assessment of Holt-Winters exponential smoothing and ARIMA for inventory optimization in supply chains. Kumar & Khedlekar (2024)**	**Optimizing inventory systems with RFID: A narrative review of integration, efficiency, and barriers Budiyanto & Muslim (2024)**	**Implementation of Economic Order Quantity and Reorder Point methods in inventory management information systems Setyadi et al. (2024)**	**Last-mile logistics with alternative delivery locations: A systematic literature review. Pourmohammadreza et al. (2025)**	**Impact of Internet of Things (IoT) on Inventory Management: A Literature Survey Mashayekhy, Y., et al. (2022)**	**The model proposed in this research**
Component 0: Problem Diagnosis							
- Literature Review:	✓	✓	✓	✓	✓	✓	✓
- Engineering Tool: High stockout rate, long lead time, low inventory accuracy	✓	✗	✓	✓	✗	✓	✓
- Case Study: Telecommunication sector in Perú and international benchmarks	✗	✗	✗	✓	✗	✗	✓
- Metric: Stockout rate 26.6%, lead time 7.2 days, inventory accuracy 80.2%	✗	✓	✗	✓	✗	✗	✓
Component 1: Identification and implementation of tools							
- Literature Review:	✓	✓	✓	✓	✓	✓	✓
- Engineering Tool: ABC classification EOQ & ROP, forecasting (Holt - Winters), RFID/IoT	✓	✓	✓	✓	✗	✓	✓
- Case Study: Real-Time Inventory Management Optimization Model for Last - Mile Contractors in a Telecommunications Company	✓	✗	✗	✗	✗	✓	✓
- Metric: Reduction of overstock and stockout cost, decrease in replenishment lead time, increase in inventory availability	✗	✓	✗	✓	✗	✗	✓
Component 2: Validation and control							

- Literature Review:	✓	✓	✓	✗	✓	✓	✓
- Engineering Tool: Forecasting Validation (MAPE, ARIMA vs. Holt- Winters), RFID tracking tests	✗	✓	✗	✗	✗	✓	✓
- Case Study: Real-Time Inventory Management Optimization Model for Last - Mile contractors in a Telecommunications Company	✗	✓	✗	✓	✗	✓	✓
- Metric: Service level ≥ 95%, stockout reduction to = 8%, increase in inventory accuracy ≥ 90%, reduction in replenishment lead time.	✗	✗	✗	✓	✗	✗	✓
Total	**6**	**8**	**5**	**9**	**3**	**8**	**12**