International Journal of Scientific Research & Engineering Trends
Volume 12, Issue1, Jan-Feb-2026, ISSN (Online): 2395-566X

Streamlining Biomedical Inventory Management Practices Across Delhi Government Hospitals: A Process Optimization Framework

Sarvpriya Singh[1*], Dr. K. Pradeep Reddy[2]
[1,2] Sanjeev Agrawal Global Educational(SAGE) University
[1]sarvpriya.del@hotmail.com, [2] kpradeep.r@sageuniversity.edu.in

Abstract-Biomedical inventory management is an essential component of healthcare service delivery because the availability of medicines, medical consumables, diagnostic supplies, and essential equipment directly affects operational continuity and patient care. Government hospitals must balance uninterrupted availability with limited budgets, uncertain demand, procurement lead times, storage constraints, and the risk of inventory expiry or obsolescence. In Delhi, the Comptroller and Auditor General of India's performance audit of public health infrastructure and management identified issues relating to the availability of drugs, medicines, equipment, and other consumables, highlighting the need for stronger procurement and inventory-control mechanisms.
This paper proposes an integrated process optimization framework for streamlining biomedical inventory management across Delhi Government Hospitals. The framework combines ABC–VED classification, demand forecasting, criticality-weighted replenishment, minimum–maximum stock control, first-expiry-first-out (FEFO) issuing, centralized visibility of inventory, inter-hospital stock redistribution, and performance-based procurement monitoring. A mathematical optimization model is developed to minimize total inventory-related cost while penalizing stockouts, expiry losses, emergency procurement, and delayed replenishment. A multi-hospital, quasi-experimental evaluation design is proposed to assess the framework against existing inventory practices. An illustrative numerical scenario demonstrates how stock availability, inventory holding, wastage, and procurement responsiveness could be evaluated. The numerical results are hypothetical and are not observations from Delhi hospitals. The proposed framework provides a basis for a data-driven, transparent, and scalable inventory management system that can support more consistent availability of essential healthcare supplies.

Keywords: Biomedical inventory management, Delhi Government Hospitals, healthcare supply chain, inventory optimization, ABC–VED analysis, stockout prevention, demand forecasting, FEFO, procurement efficiency, process optimization.

1. INTRODUCTION

1. Background of the study

Healthcare organizations depend on the timely availability of medicines, surgical consumables, diagnostic reagents, laboratory materials, medical devices, and equipment-related supplies. Any interruption in the supply of essential items may delay clinical procedures, increase operational costs, and place additional pressure on hospital staff.

Biomedical inventory management involves planning, procurement, receiving, inspection, storage, distribution, utilization monitoring, replenishment, and disposal of expired or unusable stock. Unlike conventional commercial inventory, hospital inventory must account for clinical criticality, patient safety, regulatory requirements, variable demand, product shelf life, and the consequences of non-availability.

In Delhi Government Hospitals, inventory management operates within a public healthcare system involving hospitals, designated procurement authorities, suppliers, hospital stores, pharmacies, laboratories, and clinical departments. Coordination across these entities is necessary to ensure that purchasing decisions reflect actual consumption and clinical requirements.

The CAG's Performance Audit on Public Health Infrastructure and Management of Health Services documented deficiencies relating to the availability of drugs, medicines, equipment, and other consumables during the audit period 2016–17 to 2021–22. The report also discussed procurement and distribution challenges, providing a documented rationale for examining inventory processes and coordination mechanisms in the Delhi public healthcare system.

© 2026 IJSRET

These findings establish the relevance of the research problem, although they do not establish the current performance of every Delhi Government Hospital or demonstrate the effectiveness of the framework proposed in this paper.

2. Problem Statement

Traditional inventory practices can become inefficient when consumption records, procurement schedules, supplier lead times, stock balances, and expiry information are maintained separately. This fragmentation may lead to simultaneous shortages and excess stock across different hospitals.

The principal operational problems addressed in this study are:

- Inaccurate estimation of consumption and future requirements.
- Delayed replenishment due to procurement and approval bottlenecks.
- Uneven distribution of available stock across hospitals.
- Excessive safety stock for low-priority items and inadequate buffers for critical items.
- Expiry-related wastage and inadequate batch-level visibility.
- Limited real-time monitoring of stockouts, pending orders, and supplier performance.
- Inconsistent inventory reporting and accountability across hospital departments.

These are proposed problem areas for investigation rather than claims that each condition exists in every participating hospital.

3. Research Objectives

The study has six objectives:

- To identify the major operational bottlenecks in biomedical inventory management across Delhi Government Hospitals.
- To develop a standardized inventory classification and replenishment framework based on financial value, clinical criticality, demand, and lead-time variability.
- To formulate a mathematical model for minimizing inventory costs while protecting the availability of essential supplies.
- To propose a coordinated inventory visibility and inter-hospital redistribution mechanism.
- To establish measurable performance indicators for evaluating inventory availability, wastage, procurement efficiency, and service levels.
- To design an empirical evaluation that compares the proposed framework with existing inventory management practices.

4. Research Questions

- **RQ1:** Which inventory management and procurement processes contribute most to stockouts, excess inventory, and expiry-related wastage?
- **RQ2:** How can clinical criticality and demand variability be incorporated into replenishment decisions?
- **RQ3:** To what extent can coordinated inventory visibility and inter-hospital redistribution improve inventory availability and utilization?
- **RQ4:** How can process optimization reduce total inventory-related costs without compromising the availability of essential medical supplies?

5. Research Hypotheses

- **H1:** Implementation of the proposed framework will reduce the stockout rate relative to existing inventory practices.
- **H2:** The framework will reduce the proportion of inventory lost through expiry or obsolescence
- **H3:** Criticality-weighted replenishment will improve the service level of clinically essential items.
- **H4:** Improved inventory visibility and coordinated redistribution will reduce emergency procurement and inter-hospital inventory imbalance.

These hypotheses must be tested using observed hospital-level data. No hypothesis is treated as empirically confirmed in this conceptual draft.

6. Significance of the Study

The study has potential implications for hospital administrators, procurement authorities, pharmacists, store managers, biomedical engineers, finance departments, and public health policymakers. It integrates operational and clinical priorities into a common decision framework, enabling inventory decisions to be evaluated using consistent performance indicators.

II. LITERATURE REVIEW

1. Inventory Management in Healthcare

Inventory management in healthcare differs from conventional inventory control because the consequences of a stockout are not limited to financial loss. An unavailable medicine, diagnostic reagent, or critical consumable can interrupt care delivery. Accordingly, healthcare inventory systems must balance holding costs against clinical service requirements.

© 2026 IJSRET

Traditional inventory techniques include economic order quantity (EOQ), reorder-point systems, safety-stock calculation, ABC classification, and periodic review. EOQ helps balance ordering and holding costs, while reorder-point methods determine when replenishment should begin. However, these approaches require adaptation when demand is intermittent, lead times are uncertain, and clinical criticality differs substantially across products.

2. ABC and VED Classification

ABC analysis classifies inventory according to annual consumption value. Class A items represent a relatively small proportion of items but a substantial share of annual inventory expenditure; Class C items generally account for a larger number of items but a smaller share of expenditure.

VED classification groups items according to clinical criticality:

- **Vital :** Non-availability may seriously affect patient care or essential clinical operations.
- **Essential :** Important for routine service delivery, with some possibility of temporary substitution.
- **Desirable :** Useful items whose short-term absence may have comparatively limited clinical consequences.

Combining ABC and VED provides a more balanced approach than financial classification alone. For example, a low-cost but life-critical consumable may deserve a higher service-level target than a more expensive, non-critical item.

The proposed framework extends this principle by incorporating demand variability, lead time, expiry risk, and stock redistribution opportunities.

3. Demand Forecasting and Replenishment

Demand forecasting estimates future inventory requirements using historical consumption, seasonal variation, service volumes, and known changes in clinical activity. Moving averages and exponential smoothing can provide transparent baselines. More complex models may be appropriate when consumption patterns exhibit strong seasonality or intermittent demand.

Forecast accuracy alone is not sufficient to establish inventory effectiveness. Forecasts must be translated into replenishment decisions that account for stock on hand, open purchase orders, pending deliveries, safety stock, and clinically acceptable shortage risk.

A suitable evaluation should therefore compare both forecasting performance and downstream inventory outcomes, such as stockout frequency, emergency purchasing, expiry losses, and service levels.

4. Expiry Management and FEFO

Expiry management is particularly important for medicines, reagents, sterile consumables, and other time-sensitive healthcare products. First-expiry-first-out (FEFO) prioritizes issuing stock with the earliest expiry date, irrespective of the date of receipt.

The World Health Organization's standard operating procedures describe FEFO as a stock management practice and recommend recording batch or lot numbers, expiry dates, and storage locations.

The proposed framework uses FEFO at the point of issue and adds expiry-risk alerts to support timely consumption, transfer, or other authorized corrective action.

5. Public Procurement and Supply-Chain Coordination

Government procurement requires transparent procedures, documented approvals, supplier accountability, and compliance with applicable financial and procurement rules. The Government of India's Manual for Procurement of Goods, Second Edition 2024 provides an important policy reference for public procurement processes.

In a multi-hospital environment, procurement efficiency depends on the quality of demand estimates, the timely initiation of procurement, supplier performance, contract availability, and coordination between central procurement authorities and individual hospitals.

The Delhi CAG performance audit reported procurement and supply-related concerns, including shortages and delays involving medical supplies. These findings make procurement-process analysis relevant to Delhi's public healthcare context.

6. Inventory Visibility and Information Systems

Inventory visibility refers to the ability to obtain reliable information about stock quantities, expiry dates, reserved quantities, pending orders, consumption, and available stock across storage locations.

The United Nations Development Programme's health-product inventory guidance emphasizes monitoring consumption, stock on hand, stock on order, expiry dates, and stockout or expiry risks. It also highlights the value of regular inventory supervision and accurate reporting.

A coordinated digital inventory system could make these practices more consistent across hospitals. However, technology alone cannot resolve inaccurate records, unclear responsibilities, delayed approvals, or poor adherence to standard operating procedures. Data quality and governance are therefore essential parts of the proposed framework.

7. Procurement Bottlenecks in Public Healthcare

Research on government medical-equipment procurement has also highlighted long procurement lead times and process

© 2026 IJSRET

bottlenecks. Garg et al. examined bottlenecks in the procurement process of a central equipment procurement agency in India, illustrating the importance of examining procedural delays rather than treating inventory shortages solely as a forecasting problem.

Equipment procurement and recurring consumable replenishment have different operational characteristics. Consequently, equipment-related findings should inform the broader process analysis without being assumed to apply identically to every inventory category.

8. Summary of the Literature

Research Theme	Main Contribution	Relevance to the proposed study
ABC–VED classification	Differentiates financial value and clinical criticality	Establishes differentiated service-level targets
Forecasting and replenishment	Estimates future demand and reorder requirements	Reduces reactive ordering and shortages
FEFO and expiry control	Prioritizes stock according to expiry date	Reduces preventable expiry losses
Public procurement	Emphasizes procedural compliance and supplier accountability	Supports procurement-delay analysis
Process optimization	Identifies bottlenecks and standardizes workflows	Integrates the above practices into one framework

The literature and policy sources support the components of the proposed framework. They do not, by themselves, demonstrate that the combined framework will produce a particular percentage reduction in stockouts or costs in Delhi hospitals.

IV. RESEARCH GAP

Although inventory classification, forecasting, procurement planning, expiry management, and digital inventory systems are established approaches, a practical challenge remains: these techniques are often considered separately rather than as components of one coordinated hospital-wide process.

The review identifies the following research gaps.

Gap-1 : Limited integration of financial and clinical priorities. Financial inventory classifications do not independently establish which items require the strongest protection against stockouts. A framework should combine annual consumption value with clinical criticality.

Gap-2 : Inadequate linkage between demand forecasts and procurement workflows. A forecast does not automatically generate a purchase order. The process must incorporate approval times, supplier lead times, stock on order, and procurement status.

Gap-3 : Insufficient coordination across hospital stores. When inventory information is fragmented, an item may be unavailable at one facility while usable stock exists at another. A common visibility and transfer mechanism could identify these imbalances.

Gap-4 : Weak integration of expiry risk into replenishment decisions. Conventional reorder rules may overlook existing batches that are approaching expiry. Replenishment decisions should account for remaining shelf life and expected consumption.

Gap-5 : Lack of a unified performance measurement framework. Stockouts, wastage, inventory holding, emergency procurement, order fulfilment, and lead times should be measured together to avoid improving one indicator at the expense of another.

Gap-6 : Need for systematic evaluation in the Delhi public healthcare context. The CAG audit provides a documented basis for studying procurement and availability issues, but the effectiveness of the integrated framework proposed here requires a separate empirical evaluation using appropriately collected hospital-level data.

1. Proposed Contribution

The principal contribution is a Criticality-Weighted Biomedical Inventory Optimization Framework (CW-BIOF). It integrates:

- ABC–VED inventory classification.
- Demand forecasting and uncertainty estimation.
- Dynamic safety stock and reorder points.

© 2026 IJSRET

- FEFO-based batch management.
- A centralized inventory visibility layer.
- Inter-hospital stock redistribution, subject to authorization and logistics constraints.
- Procurement lead-time and supplier-performance monitoring
- A common performance dashboard.

The contribution is an integrated, testable process design rather than a claim that an entirely new inventory algorithm has already been empirically validated.

V. PROPOSED METHODOLOGY

1. Research design

A quantitative, multi-site quasi-experimental design is proposed. The study would compare existing inventory management practices with the proposed framework over equivalent baseline and implementation periods.

A mixed-methods diagnostic stage may precede the quantitative evaluation to identify process bottlenecks and validate the proposed workflow with inventory managers, pharmacists, procurement personnel, and hospital administrators.

The research should be conducted only after obtaining institutional approvals, permission to access procurement and stock records, and any required ethics or administrative clearance.

2. Study setting and sampling

The target population comprises Delhi Government Hospitals and their relevant inventory-management units, including central stores, pharmacy stores, laboratory stores, and designated medical-consumable stores.

A feasible pilot could involve a proposed sample of 6–10 hospitals selected to represent differences in size, service profile, inventory volume, and procurement arrangements. This is a planning assumption, not a statement about actual participation or sample availability.

Where feasible, hospitals should be matched by size and service profile before allocating them to implementation and comparison groups. If randomized or matched allocation is not possible, the study should document baseline differences and adjust for relevant confounding factors.

3. Data Collection

The proposed study would collect de-identified or operational inventory data for a 12-month baseline period and a 12-month implementation period, where available and appropriate.

Data Category	Variables to Collect	Purpose
Item master	Item code, Category, Unit, Unit cost, Clinical criticality	Classification
Consumption	Daily or monthly issues, Returns, Stock adjustments	Demand estimation
Inventory balance	Opening stock, Receipts, Issues, Closing stock	Stock reconciliation
Procurement	Requisition date, Approval Date, Order date, Promised delivery date, Receipt date	Lead-time analysis
Supplier performance	Ordered quantity, Delivered quantity, Delays, Rejected supplies	Fulfilment assessment
Expiry	Batch, expiry date, Quantity expired or written off	Wastage analysis
Stockouts	Item, Start and end dates, Unfulfilled demand	Availability assessment
Redistribution	Transfer request, Dispatch, Receipt, Transfer cost	Inter-hospital coordination
Finance	Purchase cost, Carrying cost estimates, Emergency purchase cost	Cost analysis

The dataset should distinguish medicines, consumables, diagnostic reagents, and equipment-related inventory where their storage, demand, or replenishment characteristics differ.

© 2026 IJSRET

4. Data Preparation

The following procedures are proposed:

- Standardize item codes, units of measurement, and product descriptions.
- Remove duplicate transaction records while retaining an audit trail.
- Reconcile opening stock, receipts, issues, adjustments, and closing stock.
- Separate zero demand from missing data.
- Identify cancelled orders, backorders, emergency purchases, and partial deliveries.
- Validate expiry dates and batch-level balances.
- Document stockout definitions and ensure that the same definition is used across study sites.
- Record policy changes, supply disruptions, and other events that could affect the comparison.

Missing records should not automatically be interpreted as zero consumption or zero stockouts.

5. Framework Architecture

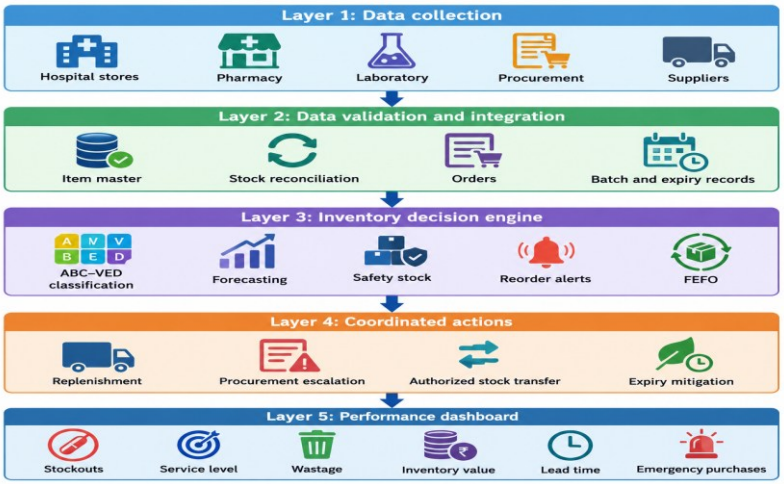


Figure 1 : Proposed Architecture of the Criticality-Weighted Biomedical Inventory Optimization Framework (CW-BIOF).

6. Inventory Classification

ABC analysis should be calculated from annual consumption value:

$$ACVi = c_i \times D_i$$

Where, c_i represents the unit cost of item i and D_i represents its annual consumption quantity.

Items are then ranked by annual consumption value and grouped into A, B, and C classes using thresholds specified before the analysis. A commonly used starting convention is approximately 70–80% of cumulative value for A items, the next 15–25% for B items, and the remainder for C items. The actual cutoffs should be adapted to the observed distribution rather than assumed to be universally optimal.

VED classification should be determined through a documented clinical review, not by price alone.

The resulting ABC–VED matrix can be used to establish replenishment priority. Vital items should receive stringent availability monitoring even when their financial value is low.

7. Demand forecasting

For items with relatively stable demand, a moving average or exponential smoothing model can be used as a baseline.

The k -period moving-average forecast is:

$$\hat{d}_{i,t} = \frac{1}{k}\sum_{j=0}^{k-1} d_{i,t-j}$$

Where, $d_{i,t}$ is the observed demand for item i during period t.

For items with seasonality, intermittent demand, or major fluctuations in clinical activity, alternative forecasting models should be evaluated against the baseline. Model selection should use rolling-origin validation rather than fitting and evaluating on the same data.

8. Replenishment and Stock Redistribution

The proposed process operates as follows:

- Review current stock, reservations, open orders, and expected deliveries.

© 2026 IJSRET

- Estimate demand during the replenishment lead time.
- Calculate the reorder point and recommended order quantity.
- Flag vital items that are likely to fall below their minimum stock level.
- Check whether safe and eligible surplus stock is available at another hospital.
- Initiate an authorized transfer if it is clinically suitable, traceable, and operationally feasible.
- If transfer is not feasible, initiate the applicable procurement procedure.
- Record delivery, inspection, batch information, and expiry dates.
- Issue stock using FEFO.
- Update the inventory dashboard and review the reason for any stockout or delayed replenishment.

Inter-hospital transfers must comply with applicable administrative, financial, product-storage, and traceability requirements. The proposed system does not assume that every item can legally or practically be transferred.

9. Implementation Phases

Phase	Proposed duration	Major activities
Phase I: Diagnostic study	Months 1–2	Process mapping, data audit, stakeholder consultation
Phase II: System configuration	Months 3–4	Item master, ABC–VED rules, KPIs, dashboard design
Phase III: Pilot implementation	Months 5–7	Training, alerts, FEFO controls, replenishment workflow
Phase IV: Monitoring	Months 8–10	Data quality reviews, corrective action, process refinement
Phase V: Evaluation	Months 11–12	Comparative analysis, cost assessment, scale-up recommendation

These durations are a proposed implementation schedule and may need to be extended to support a sufficiently powered before-and-after evaluation.

VI. MATHEMATICAL MODEL

1. Notation

Symbol	Definition
i	Inventory item
h	Hospital
t	Planning period
d_{iht}	Demand for item i at hospital h in period t
d_{iht}	Forecast demand
x_{iht}	Usable inventory at the beginning of period
q_{iht}	Replenishment quantity ordered
y_{iht}	Quantity of demand fulfilled
u_{iht}	Unmet demand
e_{iht}	Quantity expired or written off
z_{ihgt}	Quantity transferred from hospital h to hospital g
L_{ih}	Procurement lead time
c_i	Unit acquisition cost
K_i	Fixed ordering or procurement transaction cost
H_i	Inventory holding cost per unit per period
P_i	Penalty weight per unit of unmet demand
W_i	Expiry or wastage cost per unit
R_i	Unit transfer cost
v_i	Clinical criticality weight

© 2026 IJSRET

2. Demand During Lead Time

If demand is approximately independent across periods, expected demand during the procurement lead time is:

$$\mu_{L,i} = \bar{d}_i L_i$$

Where, d_i is the estimated average demand per period and L_i is the lead time expressed in the same period units.

When demand and lead time are variable and independent, an approximate lead-time demand variance is:

$$\sigma^2_{L,i} = L_i \sigma^2_{d,i} + \bar{d}_i^2 \sigma^2_{L,i}$$

Here, $\sigma_{d,i}$ denotes demand standard deviation per period, while $\sigma_{L,i}$ denotes the standard deviation of lead time. This approximation should be modified if demand and lead time are dependent or demand is strongly seasonal.

3. Safety stock and reorder point

A conventional safety-stock calculation is:

$$SS_i = z_i \sigma_{L,i}$$

where z_i is the service-level factor. Higher target service levels generally require larger safety stocks when demand uncertainty is unchanged.

The reorder point is:

$$ROP_i = \mu_{L,i} + SS_i$$

For critical inventory, the service-level factor should be selected based on clinical risk and operational feasibility. The model must also account for stock on order and reserved quantities so that inventory already expected to arrive is not unnecessarily reordered.

4. Criticality-weighted service level

Let v_i represent the normalized clinical criticality weight of item i. Define the weighted service level as:

$$SL_w = \frac{\sum_i v_i y_i}{\sum_i v_i d_i}$$

Where, y_i is demand fulfilled and d_i is total demand during the evaluation period.

This measure gives more weight to items with higher clinical criticality. It should be reported alongside the conventional unit-based service level because a weighted measure can conceal poor performance in lower-weight categories.

5. Inventory balance constraint

The inventory balance at each hospital and period is represented by:

$$x_{ih,t+1} = x_{iht} + r_{iht} + q_{iht}^{del} + \sum_g z_{ight} - \sum_g Z_{ihgt} - y_{iht} - e_{iht}$$

Where, r_{iht} represents other recorded receipts and q_{iht}^{del} represents delivered replenishment. Transfers received and dispatched are recorded separately. All terms must use consistent units and transaction timing.

In a practical implementation, batch-level balances are required to account for expiry, storage conditions, product substitution restrictions, and traceability.

6. Total Cost Minimization

The proposed optimization objective is:

$$\min Z = \sum_{i,h,t} [c_i q_{iht} + H_i x_{iht} + K_i a_{iht} + P_i v_i u_{iht} + W_i e_{iht} + \sum_g R_i z_{ihgt}$$

Where, a_{iht} is a binary variable indicating whether a procurement order is initiated. The model includes acquisition, holding, ordering, shortage, expiry, and transfer costs.

The shortage penalty $P_i v_i$ is a decision weight representing the relative operational consequence of unmet demand. It is not a monetary valuation of patient harm. Clinical safety constraints must remain in force even when a monetary objective would favor a different decision.

7. Constraints

The optimization problem is subject to:

Demand Fulfilment

$$Y_{iht} + u_{iht} = d_{iht}$$

Non-Negativity

$$x_{iht}, q_{iht}, y_{iht}, u_{iht}, e_{iht}, z_{ihg} \geq 0$$

Storage Capacity

$$\sum_i b_i x_{iht} \leq C_h$$

Where, b_i is the storage capacity consumed per unit and C_h is available storage capacity.

© 2026 IJSRET

Procurement Capacity

$$\sum_i q_{iht} \leq B_{ht}$$

Where, B_{ht} is the applicable procurement or budget constraint, interpreted consistently with the institution's financial rules.

Transfer Feasibility

Transfers must not exceed eligible available stock at the sending hospital and must respect recipient demand, product compatibility, storage requirements, and authorization constraints.

Clinical Availability Constraints

Vital items should have pre-established minimum service-level targets or explicit shortage-risk limits. The precise targets must be determined with clinical and administrative stakeholders.

8. Criticality-Weighted Reorder Policy

A practical implementation can calculate a replenishment trigger from projected inventory position:

$$IP_{iht} = OH_{iht} + OO_{iht} - RS_{iht}$$

Where, OH is usable on-hand stock, OO is confirmed outstanding supply, and RS is reserved stock.

Replenishment should be triggered when:

$$IP_{iht} \leq ROP_{ih}$$

The order quantity can then be determined using a minimum–maximum policy, subject to budget, storage capacity, shelf life, and procurement rules. Vital items may require additional exception alerts even when the aggregate inventory position appears adequate.

9. Model validation

The model should be tested using historical demand and lead-time data, followed by rolling-period simulation and a prospective pilot. Sensitivity analysis should vary demand uncertainty, supplier lead time, holding costs, expiry rates, transfer costs, and shortage penalties.

The model should be compared against at least three baselines:

- Existing hospital inventory practices.
- Conventional reorder-point replenishment.
- ABC–VED classification with fixed safety stock.

This design would help establish whether the integrated framework provides benefits beyond those obtainable through simpler inventory controls.

6. Experimental Setup

6.1 Evaluation design

The proposed framework should be evaluated through a controlled operational comparison using actual inventory records from participating hospitals.

Parameter	Proposed experimental specification
Study setting	Delhi Government Hospitals
Sampling unit	Hospital–inventory item–time period
Baseline period	12 months, where records permit
Intervention period	12 months, where feasible
Inventory categories	Medicines, medical consumables, diagnostic supplies, selected equipment-related items
Intervention	CW-BIOF inventory and process optimization
Comparison	Existing practice and conventional reorder-point policy
Primary outcome	Stockout rate
Secondary outcomes	Service level, expiry loss, emergency purchases, inventory holding, procurement lead time
Statistical approach	Difference-in-differences or matched comparison, with appropriate uncertainty estimates

The final sample size should be determined using baseline stockout rates, expected effect size, variability, clustering by hospital, and the statistical power required for the primary outcome.

2. Performance indicators

The following measures should be defined before implementation.

Stockout Rate

$$SOR = \frac{\text{Item - Periods with a Stockout}}{\text{Tota ltem Periods Observed}} \times 100$$

An item-period is considered stocked out when usable stock is insufficient to meet recorded demand during the specified period. The study must use a consistent definition across facilities.

Demand Fulfilment Rate

$$DFR = \frac{\text{Qunatity - supplied against demand}}{\text{Tota quantity demanded}} \times 100$$

© 2026 IJSRET

Expiry Loss Rate

$$ELR = \frac{\text{Value of expired or written - off inventory}}{\text{Value of inventory issued or consumed}} \times 1$$

The denominator must be specified consistently; an alternative measure based on inventory available during the period may be reported as a sensitivity analysis.

Average Inventory Value

$$AIV = \frac{1}{T}\sum_{t=1}^{T} IV_t$$

Where, IVt is the recorded inventory value at time t.

Procurement Lead Time

PLT=Date of receipt - Date of approved order

The study should separately report requisition-to-approval time and approval-to-delivery time to identify where delays arise.

Emergency Procurement Ratio

$$EPR = \frac{\text{Value of emergency Purchase}}{\text{Total Procurement Value}} \times 100$$

6.3 Statistical Analysis

The analysis should include descriptive statistics, before-and-after comparisons, confidence intervals, and sensitivity analysis.

For hospitals with comparable baseline and intervention data, a difference-in-differences model can be used:

$$Y_{ht} = \beta_0 + \beta_1 T_h + \beta_2 Post_t + \beta_3 (T_h + Pos$$

Here, Y_{ht} is the outcome for hospital h in period t, T_h indicates intervention-group membership, and $Post_t$ indicates the post-implementation period. The coefficient β_3 estimates the intervention-associated change under the model's assumptions.

Hospital and time effects, seasonality, changes in demand, supply disruptions, and other relevant covariates should be incorporated as appropriate. Standard errors should account for clustering at the hospital level.

Where the number of hospitals is small, conventional cluster-robust inference may be unreliable; alternative small-sample methods or a carefully designed interrupted time-series analysis may be more appropriate.

VII. RESULTS WITH GRAPHS AND TABLES

1. Status of the results

The following tables and graph are an illustrative demonstration of how results could be presented. They are not findings from a completed hospital intervention, and the figures must not be represented as measured outcomes from Delhi Government Hospitals.

For demonstration, assume a hypothetical baseline stockout rate of 10% and a post-implementation rate of 4%. These values are chosen solely to illustrate the calculations.

2. Illustrative stockout-rate comparison

Illustrative stockout-rate comparison

Hypothetical figures for demonstrating the proposed evaluation; not observed Delhi hospital data.

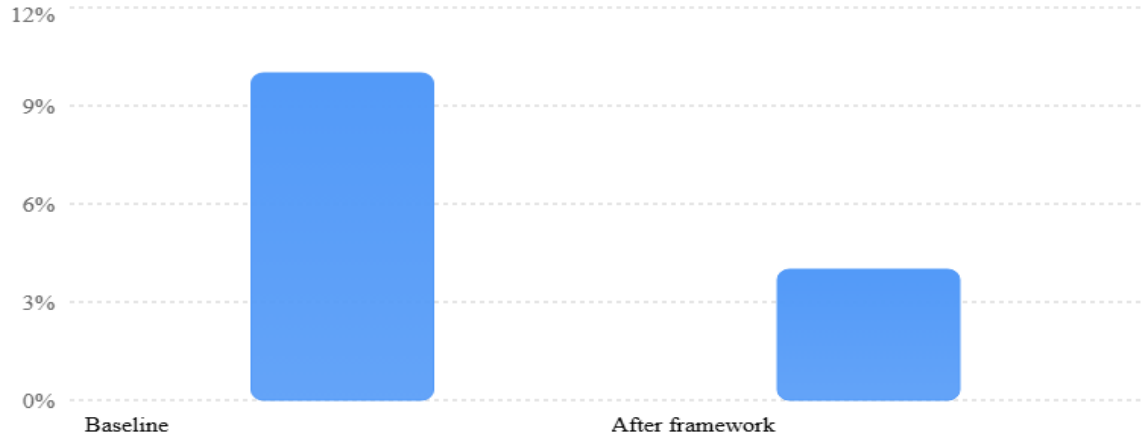


Figure 2 : Hypothetical Comparison of Stockout Rates before and after Implementation

© 2026 IJSRET

The illustrative absolute change is:

10% - 4% = 6 percentage points

The illustrative relative reduction is:

$$\frac{10-4}{10} X100 = 60\%$$

Thus, the example demonstrates how a six-percentage-point decline would correspond to a 60% relative reduction from the assumed baseline. It does not establish that CW-BIOF achieves this reduction in practice.

3. Illustrative Summary of Inventory Performance

Table-2 : Presents a Template Populated with Hypothetical Values to Demonstrate the Reporting Format

Performance indicator	Illustrative baseline	Illustrative post-implementation	Direction sought
Stockout rate	10.0%	4.0%	Decrease
Demand fulfilment rate	90.0%	96.0%	Increase
Expiry loss rate	3.0%	1.5%	Decrease
Emergency procurement ratio	12.0%	7.0%	Decrease
Average procurement lead time	30 days	24 days	Decrease
Inventory holding value	₹100 lakh	₹90 lakh	Decrease, if service is maintained
Critical-item service level	95.0%	99.0%	Increase

Table 2. Illustrative performance dashboard. All values are hypothetical and require replacement with observed data.

The values are internally illustrative rather than statistically estimated. No sample size, confidence interval, p-value, or causal effect can be inferred from this table.

4. Illustrative comparison of inventory strategies

A proper evaluation should compare the proposed framework with conventional alternatives rather than relying solely on a before-and-after comparison.

Table 3. Conceptual comparison of the inventory strategies; this is a design comparison, not an empirical ranking

Evaluation Dimension	Existing Practice	Conventional Reorder Point	Proposed CW-BIOF
Demand estimation	Existing method	Forecast-based	Forecast adjusted for uncertainty
Clinical criticality	Depends on current practice	Not inherently included	Explicitly included
Expiry management	Existing procedure	Requires additional rules	Batch-level FEFO and alerts
Inter-hospital visibility	Existing arrangement	Not inherent	Coordinated visibility layer
Replenishment	Existing workflow	Stock-triggered	Stock-triggered with criticality and lead-time adjustments
Evaluation	Existing KPIs	Service and cost measures	Integrated clinical and operational KPIs

5. Proposed Results Reporting Template

When actual data are available, the primary results table should report effect estimates and their uncertainty.

Table 4. Template for the final statistical analysis. Values should be populated only after the empirical evaluation.

Outcome	Baseline	Intervention	Adjusted Effect	95% CI	p-value
Stockout rate	To be measured	To be measured	To be estimated	To be calculated	To be calculated
Demand fulfilment	To be measured	To be measured	To be estimated	To be calculated	To be calculated
Expiry loss rate	To be measured	To be measured	To be estimated	To be calculated	To be calculated
Emergency procurement ratio	To be measured	To be measured	To be estimated	To be calculated	To be calculated
Procurement lead time	To be measured	To be measured	To be estimated	To be calculated	To be calculated

© 2026 IJSRET

7.6 Cost–Benefit Analysis

The financial evaluation should compare annualized implementation costs with demonstrable savings.

Net Benefit=Avoided Costs-Implementation Costs

Avoided costs may include reduced expiry losses, fewer emergency purchases, lower avoidable holding costs, and reduced transfer inefficiencies. Costs should include software, equipment, staff training, data cleaning, maintenance, and additional logistics.

The return on investment can be estimated as:

$$\text{ROI} = \frac{\text{Net Benefit}}{\text{Implementation Cost}} \times 100$$

The analysis should avoid double-counting savings. For example, reduced inventory value and reduced holding costs are not necessarily independent benefits. Any claimed savings should be calculated from actual financial records and an explicitly defined counterfactual.

VIII. DISCUSSION

1. Interpretation of the Proposed Framework

The principal implication of CW-BIOF is that biomedical inventory management should be treated as a coordinated process rather than as a collection of independent store-level activities.

A stockout may originate in inaccurate demand estimation, delayed requisition approval, supplier non-performance, incorrect inventory records, or a distribution imbalance. Improving one stage alone may not resolve the overall problem. The proposed framework makes these dependencies visible and assigns measurable indicators to each stage.

The CAG's audit findings provide a relevant public-sector rationale for investigating inventory availability, procurement delays, and distribution coordination in Delhi. However, the magnitude and causes of present-day inventory problems should be established from the study's own data rather than extrapolated from historical audit findings.

2. Role of Criticality-Weighted Inventory Control

The integration of ABC and VED classifications can support differentiated inventory policies. High-value items may need tighter financial control, while vital items require stronger availability safeguards irrespective of price.

This differentiation is important because minimizing expenditure does not necessarily minimize clinical risk. A model that reduces inventory value by allowing critical items to become unavailable would be operationally unacceptable. Consequently, clinical availability constraints should take priority over purely financial optimization.

3. Procurement Efficiency and Accountability

The Government of India's procurement manual emphasizes transparency, value for money, need assessment, procurement planning, contract management, and supplier-related controls. These principles support the inclusion of approval times, delivery performance, and procurement status in the proposed inventory framework.

A practical implementation should distinguish between delays that can be resolved within a hospital and those that require intervention by a designated procurement authority. This distinction would make the dashboard more useful for corrective action and reduce the risk of assigning responsibility to the wrong organizational unit.

4. Expiry Reduction and Stock Redistribution

FEFO procedures and expiry alerts can improve stock rotation, provided that batch-level information is accurate and staff follow the prescribed issuing process.

Coordinated visibility may also identify stock that can be transferred to a hospital with a corresponding need. Such transfers should not be automatic: they must consider remaining shelf life, expected consumption, transport conditions, compatibility, and authorization.

The potential benefit is therefore not simply moving stock between facilities, but making more effective use of available, safe, and clinically appropriate inventory.

5. Digital Transformation and Governance

A shared dashboard can provide visibility of stock balances, open orders, stockout alerts, expiry risks, and supplier delays. However, a digital system cannot compensate for missing transactions or inconsistent item codes.

The implementation should include:

- Standard operating procedures and a common item master.
- Role-based access and an auditable transaction history.
- Periodic physical stock verification.
- Staff training and designated data owners.
- Escalation rules for critical shortages.
- Periodic review of model performance and alert thresholds.

The system should also preserve existing statutory procurement and financial approval requirements.

© 2026 IJSRET

Automated recommendations must not bypass applicable authorization procedures.

6. Policy and Managerial Implications

For hospital administrators, the framework provides a basis for reviewing inventory performance through a common dashboard. For procurement authorities, it provides demand and lead-time evidence that can support procurement planning. For policymakers, it offers a structured approach for identifying which process stages require investment, standardization, or accountability measures.

A phased implementation is preferable to immediate system-wide deployment. A pilot can test data quality, staff workload, transfer feasibility, and clinical availability before the framework is expanded.

7. Contribution to Research

The proposed study connects inventory optimization with healthcare process management. Its main research contribution is the integration of financial classification, clinical criticality, replenishment uncertainty, expiry management, and inter-hospital coordination within a single evaluable framework.

Its empirical contribution will depend on whether the subsequent study uses real operational data, an appropriate comparison design, transparent statistical analysis, and reproducible definitions of the outcome measures.

IX. LIMITATIONS

The proposed framework has several limitations.

1. Absence of Primary Empirical Data : The present paper does not contain original hospital-level inventory observations. The numerical examples are illustrative and cannot establish actual performance or causal effects.

2. Data Quality Constraints : Missing transactions, inconsistent item codes, unrecorded stockouts, and incomplete batch information may affect forecasting accuracy and performance estimates.

3. Variation Among Hospitals : Hospitals differ in size, clinical specialization, demand patterns, procurement arrangements, and storage capacity. A common framework will require local configuration.

4. Uncertain Demand and Lead Times : Demand spikes, supplier delays, public-health emergencies, and changing clinical requirements may reduce the reliability of forecasts and reorder points.

5. Clinical Criticality Assessment : VED classification requires expert review and periodic revision. Inconsistent classification may lead to inappropriate stock priorities.

6. Implementation Costs : Digital infrastructure, integration with existing systems, staff training, and ongoing data governance may require substantial resources.

7. Redistribution Constraints. Not all inventory can be transferred between hospitals. Product compatibility, cold-chain conditions, remaining shelf life, traceability, and administrative authorization may limit redistribution.

8. Generalizability : Results from a pilot may not automatically generalize to every Delhi Government Hospital or to other public healthcare systems.

9. Evaluation Period : A short implementation period may not capture seasonal demand, rare shortages, or long procurement cycles.

10. Optimization Assumptions : Simplified cost functions may not fully represent clinical consequences, supplier behavior, or complex operational constraints. The model should be refined using stakeholder input and validated against observed decisions.

X. CONCLUSION

This paper proposes the Criticality-Weighted Biomedical Inventory Optimization Framework (CW-BIOF) for streamlining biomedical inventory management across Delhi Government Hospitals. The framework integrates ABC–VED classification, demand forecasting, safety-stock calculation, reorder-point replenishment, FEFO-based expiry control, coordinated inventory visibility, inter-hospital redistribution, and procurement-performance monitoring.

The mathematical model balances acquisition, ordering, holding, expiry, shortage, and transfer costs while allowing clinical criticality to influence replenishment priorities. The proposed experimental design establishes a pathway for evaluating stockout rates, service levels, expiry losses, emergency procurement, inventory holding, and procurement lead times against existing practices.

The study is motivated by documented public-sector procurement and supply challenges, but the effectiveness of the proposed framework remains to be empirically established. The illustrative results in this draft are not actual findings from Delhi hospitals. Future research should use audited hospital-level records, an appropriate comparison design, and transparent statistical reporting to determine whether the framework improves inventory availability and cost efficiency.

Ultimately, streamlining biomedical inventory management requires both technological support and process discipline. Standardized records, clinically informed replenishment, accountable procurement workflows, and reliable performance measurement can form the foundation of a more coordinated and responsive public healthcare supply chain.

REFERENCES

1. Comptroller and Auditor General of India. (2024). Performance Audit on Public Health Infrastructure and Management of Health Services. Report No. 3 of 2024,

© 2026 IJSRET

Government of NCT of Delhi. Available at: CAG of India official website.

2. Department of Expenditure, Ministry of Finance, Government of India. (2024). Manual for Procurement of Goods, Second Edition, 2024. New Delhi: Government of India. Available at: Official procurement manual (PDF).
3. United Nations Development Programme. (n.d.). Inventory Management. Health Implementation Manual: Health Product Management. Available at: UNDP inventory management guidance.
4. World Health Organization. (2022). Standard Operating Procedures. Guidance covering storage and inventory practices, including first-expiry-first-out (FEFO). Available at: WHO standard operating procedures (PDF).
5. Garg, N., Garg, R., Das, A., & Pandey, S. (2026). Identifying bottlenecks in the medical equipment procurement process of Central Equipment Procurement Agency of Government of India (GOI) and suggesting remedial measures. Medical Journal Armed Forces India, 82(3), 267–275. https://doi.org/10.1016/j.mjafi.2024.09.006.
6. M. Hussain, V. Siddharth, and S. Arya, "ABC, VED and lead time analysis in the surgical store of a public sector tertiary care hospital in Delhi," Indian Journal of Public Health, vol. 63, no. 3, pp. 194–198, 2019, doi: 10.4103/ijph.IJPH_282_18.
7. M. Devnani, A. K. Gupta, and R. Nigah, "ABC and VED analysis of the pharmacy store of a tertiary care teaching, research and referral healthcare institute of India," Journal of Young Pharmacists, vol. 2, no. 2, pp. 201–205, 2010, doi: 10.4103/0975-1483.63170.
8. T. Anand, G. K. Ingle, J. Kishore, and R. Kumar, "ABC-VED analysis of a drug store in the Department of Community Medicine of a Medical College in Delhi," Indian Journal of Pharmaceutical Sciences, vol. 75, no. 1, pp. 113–117, 2013, doi: 10.4103/0250-474X.113543.
9. R. Gupta, K. K. Gupta, B. R. Jain, and R. K. Garg, "ABC and VED analysis in medical stores inventory control," Medical Journal Armed Forces India, vol. 63, no. 4, pp. 325–327, 2007, doi: 10.1016/S0377-1237(07)80006-2.
10. S. Kumar and A. Chakravarty, "ABC-VED analysis of expendable medical stores at a tertiary care hospital," Medical Journal Armed Forces India, vol. 71, no. 1, pp. 24–27, 2015, doi: 10.1016/j.mjafi.2014.07.002.
11. S. Kant, P. Haldar, A. Singh, and A. Kankaria, "Inventory management of drugs at a secondary level hospital associated with Ballabgarh HDSS—An experience from North India," Journal of Young Pharmacists, vol. 7, no. 2, 2015, doi: 10.5530/jyp.2015.2.9.
12. S. Singh, A. K. Gupta, and D. M. Latika, "ABC and VED analysis of the pharmacy store of a tertiary care, academic institute of Northern India to identify the categories of drugs needing strict management control," Journal of Young Pharmacists, vol. 7, no. 2, pp. 76–80, 2015, doi: 10.5530/jyp.2015.2.4.
13. A. B. Kulkarni, S. Dudhgaonkar, and P. Uike, "ABC-VED matrix—a dual approach to efficient inventory control at a tertiary care teaching hospital in India," International Journal of Basic & Clinical Pharmacology, vol. 14, no. 5, pp. 706–710, 2025, doi: 10.18203/2319-2003.ijbcp20252565.
14. N. Legese, T. Teshome, and T. Gedif, "Inventory management of health commodities in a tertiary teaching hospital in Ethiopia," Frontiers in Pharmacology, vol. 13, Art. no. 763909, 2022, doi: 10.3389/fphar.2022.763909.
15. Z. Ceylan and S. Bulkan, "Drug inventory management of a pharmacy using ABC and VED analysis," Eurasian Journal of Health Technology Assessment, vol. 2, no. 1, pp. 14–18, 2017.
16. R. H. Teunter, A. A. Syntetos, and M. Z. Babai, "Intermittent demand: Linking forecasting to inventory obsolescence," European Journal of Operational Research, vol. 214, no. 3, pp. 606–615, 2011, doi: 10.1016/j.ejor.2011.05.018.
17. J. D. Croston, "Forecasting and stock control for intermittent demands," Journal of the Operational Research Society, vol. 23, no. 3, pp. 289–303, 1972, doi: 10.2307/3007885.
18. A. A. Syntetos and J. E. Boylan, "The accuracy of intermittent demand estimates," International Journal of Forecasting, vol. 21, no. 2, pp. 303–314, 2005, doi: 10.1016/j.ijforecast.2004.10.001.
19. A. A. Syntetos and J. E. Boylan, "On the stock control performance of intermittent demand estimators," International Journal of Production Economics, vol. 103, no. 1, pp. 36–47, 2006, doi: 10.1016/j.ijpe.2005.04.004.
20. R. H. Teunter and A. A. Syntetos, "On the variance of intermittent demand estimates," International Journal of Production Economics, vol. 128, no. 2, pp. 546–555, 2010, doi: 10.1016/j.ijpe.2010.07.005.
21. R. Ramanathan, "ABC inventory classification with multiple-criteria using weighted linear optimization,"

© 2026 IJSRET

Computers & Operations Research, vol. 33, no. 3, pp. 695–700, 2006, doi: 10.1016/j.cor.2004.07.014.

22. L. V. Tavares and L. T. Almeida, "A binary decision model for the stock control of very slow moving items," Journal of the Operational Research Society, vol. 34, pp. 249–252, 1983.
23. A. F. Veinott and H. M. Wagner, "Computing optimal (s, S) inventory policies," Management Science, vol. 11, 1965.
24. J. D. C. Little, "A proof for the queuing formula: \(L=\lambda W\)," Operations Research, vol. 9, no. 3, pp. 383–387, 1961, doi: 10.1287/opre.9.3.383.
25. R. B. Chase, F. R. Jacobs, and N. J. Aquilano, Operations Management for Competitive Advantage, 10th ed. New York, NY, USA: McGraw-Hill/Irwin, 2004.
26. E. A. Silver, D. F. Pyke, and R. Peterson, Inventory Management and Production Planning and Scheduling, 3rd ed. New York, NY, USA: Wiley, 1998.
27. D. Simchi-Levi, P. Kaminsky, and E. Simchi-Levi, Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, 3rd ed. New York, NY, USA: McGraw-Hill/Irwin, 2008.
28. S. Chopra and P. Meindl, Supply Chain Management: Strategy, Planning, and Operation, 6th ed. Boston, MA, USA: Pearson, 2016.
29. J. Heizer, B. Render, and C. Munson, Operations Management: Sustainability and Supply Chain Management, 12th ed. Harlow, U.K.: Pearson, 2017.
30. J. Boylan and A. Syntetos, "Inventory management and forecasting," in Intermittent Demand Forecasting: Context, Methods and Applications. Hoboken, NJ, USA: Wiley, 2021, doi: 10.1002/9781119135289.ch2.
31. World Health Organization, Inventory and Maintenance Management Information System for Medical Devices. Geneva, Switzerland: WHO, 2025. [Online]. Available: https://www.who.int/publications/b/74278
32. World Health Organization, Introduction to Medical Equipment Inventory Management. Geneva, Switzerland: WHO, 2011.
33. World Health Organization, Standard Operating Procedures. Geneva, Switzerland: WHO, 2022. [Online]. Available: https://iris.who.int/bitstream/handle/10665/360835/9789240049581-eng.pdf?sequence=1
34. Department of Expenditure, Ministry of Finance, Government of India, Manual for Procurement of Goods, 2nd ed. New Delhi, India: Government of India, 2024. [Online]. Available: https://doe.gov.in/files/circulars_document/Manual_Goods_2024.pdf
35. United Nations Development Programme, "Inventory management," Health Implementation Manual: Health Product Management. [Online]. Available: https://healthimplementation.undp.org/functional-areas/health-product-management/inventory-management/

© 2026 IJSRET