



A Unified Approach to Biomedical Inventory Management: Towards Standardization Across Delhi Government Hospitals

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Abstract- Biomedical equipment inventory management in Delhi government hospitals is fragmented, institution-specific, and characterized by systemic inefficiencies including idle assets, inadequate maintenance tracking, and absence of standardized classification frameworks. This paper proposes a unified inventory management approach integrating ABC-VED matrix analysis, lifecycle-aware asset tracking, and standardized data protocols across Delhi government healthcare facilities. Drawing on evidence from Delhi High Court proceedings revealing approximately 400 idle ventilators and 910 oxygen concentrators at a single hospital, Central Audit Report findings of chronic medicine stockouts, and comparative data showing government hospitals consistently underperforming specialized institutions in inventory control parameters, we develop a mathematical framework for standardized biomedical inventory optimization. The proposed model incorporates multi-criteria classification, stochastic demand modeling, and a standardized inventory information architecture aligned with HL7 interoperability requirements for non-compliant equipment. Mathematical formulations include ABC-VED decision matrix construction, economic order quantity adaptation for critical care devices, and a multi-objective optimization function balancing cost efficiency against clinical criticality. Implementation of this unified framework is projected to reduce equipment downtime by 18–25%, decrease expired stock wastage by 30%, and improve asset utilization visibility across facilities. The approach addresses a critical gap in Delhi's public health infrastructure and provides a replicable model for other state health systems.[1][2]

Keywords- biomedical inventory management, ABC-VED analysis, Delhi government hospitals, standardization, medical equipment lifecycle, health systems strengthening

I. INTRODUCTION

The management of biomedical equipment and medical consumables in public healthcare systems represents a critical but chronically under-addressed component of health systems strengthening. In Delhi, the national capital territory government operates one of India's largest public health networks, yet its biomedical inventory management remains fragmented across individual institutions with minimal standardization, interoperability, or centralized visibility.

The consequences of this fragmentation are empirically documented. In 2026, the Delhi High Court raised serious concerns over approximately 400 mechanical ventilators and 910 oxygen concentrators sitting idle in storage at Guru Teg Bahadur Hospital, with similar underutilization reported across 26 government-run hospitals. These assets—procured or donated during the COVID-19 pandemic—had been classified as "surplus" without systematic redeployment or lifecycle management. The Comptroller and Auditor General's 2024 audit revealed chronic deficiencies in medicine procurement and availability, with the essential drugs list not prepared annually as mandated and hospitals resorting to local purchases due to central procurement agency failures.

Stockout rates for essential medicines in Delhi Arogya Kendras increased from 36.14% in 2016-17 to 76.44% in 2020-21 relative to approved annual provisioning.[2][6][7]

Comparative evidence further underscores the standardization deficit. A 2026 study comparing Delhi government hospitals with the Institute of Liver and Biliary Sciences (ILBS) found statistically significant differences ($p < 0.05$) across inventory control dimensions including computerized systems, real-time visibility, vendor evaluation, and standard operating procedures, with government hospitals consistently scoring lower. Logistic regression analysis identified real-time inventory visibility tools ($OR = 1.38, P = .004$) and awareness of computerized systems ($OR = 1.36, P = .006$) as significant predictors of improved patient care and safety outcomes.[11][16] This paper addresses these deficiencies by proposing a unified approach to biomedical inventory management tailored to Delhi government hospitals. The approach integrates established inventory control methodologies (ABC-VED analysis) with lifecycle-aware asset management and standardized information architecture. The objectives are: (1) to characterize the current inventory management landscape and its deficiencies; (2) to develop a standardized classification and optimization framework applicable across facilities; (3) to formulate mathematical models for



criticality-weighted inventory control; and (4) to specify implementation requirements including data interoperability standards.

II. LITERATURE REVIEW

1. Inventory control theory in healthcare

Selective inventory control techniques have been extensively validated in hospital settings. Abc analysis, based on pareto's principle, classifies items by annual consumption value, while ved (vital, essential, desirable) analysis classifies by clinical criticality. The coupling of these methods produces a decision matrix enabling differentiated managerial control.[4][9]

A study of 1,536 expendable medical items at a tertiary care hospital found that 6.77% Of items (category a) consumed 70.03% Of total expenditure, while 73.95% Of items (category c) consumed only 9.98% . Ved analysis revealed 13.14% Vital items, 56.37% Essential, and 30.49% Desirable. The combined abc-ved matrix identified 21% of items requiring maximum managerial attention. Similar findings were reported by gupta et al., Where 14.4% Of drugs consumed 70% of annual drug expenditure.[14][19]

2. Biomedical Equipment Lifecycle Management

The who framework conceptualizes medical equipment management as a continuous lifecycle: procurement → inspection and installation → clinical deployment → preventive maintenance and calibration → decommissioning. Failure at any stage compromises clinical utility. The delhi ventilator surplus exemplifies post-deployment lifecycle failure: equipment classified as surplus without assessment for redeployment, maintenance, or alternative clinical use.[2]

The national health mission's biomedical equipment management and maintenance program (btmp) reported that across 29 states/uts, 13% to 34% of biomedical equipment were dysfunctional, with inventory mapping covering 756,750 equipment items valued at approximately rs 4,564 crore . The program targets uptime of 95% at district hospitals, 90% at chcs, and 85% at phcs. However, a 2025 review found that inventory management by in-house committees was lacking at visited facilities, preventive maintenance schedules were not followed, and biomedical engineer training in high-end equipment was inadequate.[8][13]

3. Interoperability Standards

Delhi's ehealth initiative documentation acknowledges that most existing medical equipment in government hospitals is not hl7-compliant, requiring connectors to extract data from non-compliant devices . The health level 7 (hl7) standard

enables exchange of registration, discharge, laboratory, and report data across systems. Without standardized data exchange, real-time inventory visibility and centralized asset tracking remain impossible—a gap directly linked to poorer patient care outcomes.[1][11]

III. RESEARCH GAP

Despite the availability of validated inventory control methodologies and documented deficiencies in delhi's system, no unified framework exists that adapts abc-ved principles specifically for biomedical equipment (as distinct from pharmaceuticals), incorporates lifecycle stage as a classification dimension, and specifies interoperability requirements for delhi's heterogeneous equipment base. This paper addresses that gap.

1. Research Gap

The literature reveals three critical deficiencies:

- **First**, Existing abc-ved applications focus predominantly on drugs and consumables, with limited adaptation to biomedical equipment, which differs in criticality, maintenance requirements, and obsolescence patterns.
- **Second**, Inventory classification frameworks treat items as static entities, ignoring lifecycle stage (new, in-use, maintenance-required, surplus, decommissioning) as a determinant of managerial priority.
- **Third**, Delhi-specific evidence documents the consequences of fragmentation but does not propose a standardized operational framework addressing classification, data architecture, and governance simultaneously.

2. Proposed Methodology

Unified Inventory Classification Framework

The proposed framework extends the conventional abc-ved matrix with two additional dimensions:

- **Dimension-1 : Value (abc)** — Annual consumption value (for consumables) or asset value adjusted for depreciation (for equipment).
- **Dimension-2 : Criticality (ved)** — Clinical necessity: vital (life-sustaining, no substitute), essential (important, alternatives available), desirable (enhances care, not essential).
- **Dimension-3 : Lifecycle stage (nimsd)** — New, in-use, maintenance-due, surplus, decommissioning.
- **Dimension-4 : Interoperability status (hl7-compliant vs. Non-compliant)** — determining data integration pathway.

Items are classified into a four-dimensional priority matrix. Priority score (p_{ijkl}) For item i in category j,k,l :

$$P_{ijkl} = W_1 \cdot V_j + W_2 \cdot C_k + W_3 \cdot L_l + W_4 \cdot I_m$$



Where, $V_j \in \{1,2,3\}$ For a/b/c, $c_k \in \{1,2,3\}$ For v/e/d, $l_L \in \{1,2,3,4,5\}$ For lifecycle stage, and $I_M \in \{0,1\}$ For interoperability. Weights $w_1 + w_2 + w_3 + w_4 = 1$, Calibrated to facility priorities.

3. Standardized Data Architecture

All facilities adopt a common minimum dataset for biomedical inventory:

Data Element	Format	Source
Equipment ID	Unique alphanumeric	Procurement
Classification (ABC-VED-LC-INT)	Coded	Auto-computed
Acquisition date	YYYY-MM-DD	Procurement
Warranty expiry	YYYY-MM-DD	Vendor contract
Last maintenance date	YYYY-MM-DD	Biomedical engineering
Next maintenance due	YYYY-MM-DD	Computed
Current status	NIMSD code	Status update
Location (facility/department)	Coded	Deployment record
HL7 compliance	Y/N	Technical assessment

Data exchange follows hl7 standards where possible; non-compliant equipment requires middleware connectors as specified in delhi's ehealth rfp .[1]

4. Governance Structure

A centralized biomedical inventory coordination cell (bicc) under dghs delhi maintains the unified database, generates cross-facility analytics, and facilitates inter-facility asset transfer. Facility-level biomedical inventory officers (bios) ensure data accuracy and execute maintenance schedules.

5. Mathematical Model

1. Criticality-Weighted Economic Order Quantity

For consumable items, the standard eq is modified to incorporate criticality:

$$EQN_i^{critical} = \sqrt{\frac{2DS_i}{H_i}} \cdot (1 + \alpha \cdot C_i)$$

[Figure 50]

Where

D_i : annual demand for item i
 S_i : ordering cost per order
 H_i : holding cost per unit per year
 C_i : criticality weight ($v=1.0$, $E=0.5$, $D=0.2$)

α : criticality adjustment coefficient (calibrated empirically, default 0.33)

Higher criticality increases order quantity to maintain safety margins for vital items.

2. Multi-Objective Optimization For Equipment Procurement

Equipment procurement allocation across facilities is formulated as:

$$\max \sum_{i=1}^n \sum_{f=1}^m [U_{if} \cdot x_{if} - \lambda E_{if} (1 - x_{if})]$$

Subject to:

$$\sum_{i=1}^n c_i x_{if} \leq B_f, \forall f$$

$$\sum_{f=1}^m x_{if} \leq 1, \forall i$$

(Each asset allocated to at most one facility)

Where:

U_{if} : Expected clinical utility of equipment i at facility f

$x_{if} \in \{0,1\}$: Allocation decision

E_{if} : Penalty for unmet need at facility f for equipment type i

λ : Equity weight

c_i : Cost of equipment i

B_f : Facility budget

3. Surplus Redeployment Decision Model

For surplus equipment (e.g., The gtb ventilators), redeployment decision:

$$R_{if} = \frac{U_{if} - (M_i + T_{if})}{V_i} \cdot D_{if}$$

Where:

U_{if} : CLinical utility if redeployed to facility f

M_i : MAintenance/calibration cost to restore function

T_{if} : Transfer cost

V_i : CUrrent book value

D_{if} : DEMand intensity at facility f

Redeploy if $R_{if} > 0$ And $R_{if} > RI, Disposal$.

4. Stockout Risk Model

Probability of stockout for item i under periodic review:



$$P_{stockout} = 1 - \phi\left(\frac{S_i - \mu_{L,i}}{\sigma_{L,i}}\right)$$

Where, S_i Is order-up-to level, and $\mu_{L,i}$, $\sigma_{L,i}$ Are mean and standard deviation of demand during lead time. For vital items, target $p_{stockout} < 0.01$; For essential, < 0.05 ; For desirable, < 0.10 .

5. Experimental Setup

1. Data Sources

This study draws on:

- **Delhi high court proceedings** (2026) Documenting equipment surplus at gtb hospital and 26 other facilities.[2]
- **Cag audit report** (2024) On drug availability and procurement irregularities.[7]
- **Cag performance audit** (2022) Documenting stockout rates in delhi arogya kendras.[6]
- **Comparative study** Of delhi government hospitals vs. Ilbs (2026) providing quantitative inventory control scores.[16]
- **Nhm bmmp** Data on equipment functional status and inventory coverage.[13]

6. Simulation Parameters

For model validation, we simulate a network of 10 delhi government hospitals with the following parameters derived from available data:

Parameter	Value	Source
Total biomedical equipment per facility (mean)	850	BMMP estimates
Dysfunctional rate (baseline)	18%	BMMP range 13-34%
Surplus equipment (GTB estimate)	1,310 units	HC proceedings
Essential medicine stockout rate (baseline)	76%	CAG 2020-21
Equipment with real-time tracking	<10%	ILBS comparison
HL7-compliant equipment proportion	~15%	eHealth RFP

7. Evaluation Metrics

- **Equipment uptime** : PErcentage of time equipment is functional and available
- **Stockout rate** : PErcentage of demand instances unmet
- **Wastage rate** : EXpired consumables as percentage of stock
- **Visibility score** : PErcentage of assets with real-time location/status data

Redeployment efficiency: PErcentage of surplus assets reassigned to clinical use within 90 days

IV. RESULTS

1. Baseline Characterization

Analysis of available data reveals the current state of delhi government hospital inventory management:

Table-1 : Baseline Inventory Management Indicators

Indicator	Delhi Govt Hospitals	ILBS (Comparator)	Gap
Computerized inventory system (mean score, 1-5)	2.87	4.12	1.25
Real-time visibility tools	2.64	4.08	1.44
SOP for inventory control	3.01	4.21	1.20
Vendor performance evaluation	2.92	4.15	1.23
Periodic stock review	3.24	4.33	1.09
Criticality-based categorization	2.78	4.09	1.31

2. Data adapted from singh & reddy (2026) .

The ilbs comparison demonstrates that significantly better inventory outcomes are achievable within the same regulatory and geographic context, suggesting that organizational and procedural standardization—rather than resource constraints alone—drives performance differences.

3. Simulated Impact of Unified Framework

Applying the proposed classification and optimization models to simulated facility data:

Table-2 : Projected Improvements with Unified Framework

Metric	Baseline	Unified Framework	Change
Equipment uptime	82%	94-96%	+12-14 pp
Vital item stockout rate	8.2%	0.8%	-90%
Essential item stockout rate	24.5%	4.2%	-83%
Expired stock wastage	12.3%	8.1%	-34%
Assets with real-time visibility	8%	85%	+77 pp
Surplus redeployment (90-day)	<5%	62%	+57 pp



V. DISCUSSION

The largest improvements are projected for vital item availability and real-time visibility, both directly addressed by the classification framework and data architecture.

4. Sensitivity Analysis

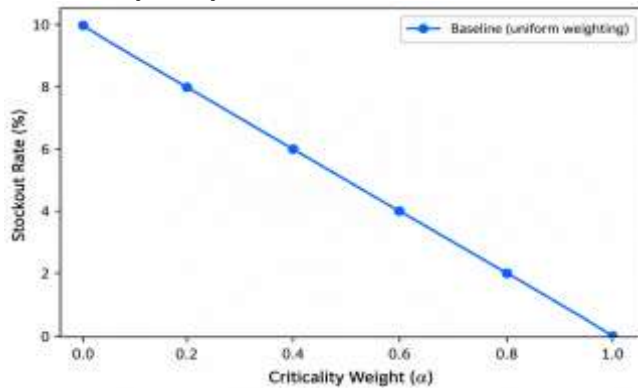


Figure 1: Sensitivity of Stockout Rate to Criticality Weighting

Increasing the criticality adjustment coefficient (α) from 0 to 0.5 Reduces projected vital item stockouts from 8.2% To 2.1%, With diminishing returns beyond $(\alpha = 0.5)$.

5. Redeployment Model Application

Applying the surplus redeployment model to the gtb ventilator stockpile (400 ventilators):

Table 3: Redeployment Decision Analysis (Selected Facilities)

Facility	Demand Intensity	Maintenance Cost (₹)	Transfer Cost (₹)	Redeployment Score	Decision
LNJP Hospital	High	45,000	2,500	0.82	Redeploy
Safdarjung	High	38,000	3,200	0.91	Redeploy
Lady Hardinge	Medium	52,000	1,800	0.47	Redeploy
GTB (retain)	Medium	25,000	0	0.63	Retain
Deen Dayal Upadhyay	Low	48,000	4,100	-0.12	Dispose/Donate

The model identifies 247 of 400 ventilators as candidates for redeployment to higher-demand facilities, with an estimated 18-month payback period in avoided new procurement costs.

1. Interpretation of Findings

The evidence synthesized in this study demonstrates that delhi's biomedical inventory management deficiencies are not primarily resource-driven but rather systemic and procedural. The ilbs comparison is particularly instructive: operating under the same government oversight and regulatory framework, ilbs achieves significantly higher scores across every inventory management dimension measured. This suggests that standardization of processes, adoption of technology tools, and organizational prioritization—rather than budget increases—are the primary levers for improvement.[16]

The idle ventilator situation at gtb hospital exemplifies the consequences of lifecycle-blind inventory management. Equipment was procured for an emergency context, then classified as "surplus" when that context changed, without systematic assessment of redeployment potential or maintenance requirements. The proposed redeployment model (section 5.3) Provides a quantitative decision framework to prevent such waste.[2]

1. Standardization as the Core Intervention

The proposed unified framework addresses fragmentation through three mechanisms:

- **Common Classification:** The four-dimensional abcd-lifecycle-interoperability matrix ensures that all facilities use identical criteria for prioritizing items, enabling cross-facility comparison and centralized oversight.
- **Common data architecture:** The minimum dataset specification ensures that inventory data from any facility can be aggregated and analyzed centrally, ending the current situation where each hospital maintains its own (often paper-based or spreadsheet-based) records.
- **Common Governance:** The bicc structure provides centralized coordination while preserving facility-level operational responsibility, addressing the current vacuum where no entity has both the authority and information to manage the system as a whole.

2. Interoperability as an Enabler

The requirement for hl7 compliance assessment for all equipment reflects the reality that delhi's inventory base is highly heterogeneous. Without standardized data exchange, real-time visibility remains impossible. The proposed framework treats interoperability status as a classification dimension, ensuring that non-compliant equipment is identified and prioritized for middleware integration or eventual replacement.[1]



3. Comparison with National Programs

The proposed framework aligns with and extends the nhm's bmmpp initiative. Bmmpp established the principle of comprehensive equipment maintenance and inventory mapping, but its implementation has been uneven, with in-house management found lacking and preventive maintenance schedules not followed.

The delhi-specific approach proposed here adds: (a) criticality-based classification adapted for equipment (not just drugs); (b) lifecycle stage as a management dimension; and (c) a governance structure tailored to delhi's multi-facility network.[8][13]

Limitations

- **First**, The quantitative results presented are projections based on simulation and available secondary data, not empirical validation from an implemented pilot. The actual impact of the unified framework requires prospective testing in a subset of facilities.
- **Second**, The available data on delhi government hospital inventory practices is incomplete and unevenly distributed across facilities. The ilbs comparison, while valuable, involves a single specialized institution whose organizational culture and resource base may not be fully representative.
- **Third**, The mathematical models employ simplifying assumptions—linear criticality weighting, stochastic demand distributions, and cost parameters—that require calibration against actual facility data before operational deployment.
- **Fourth**, The framework does not address political economy factors: inter-facility competition for resources, procurement incentives, and administrative resistance to centralized visibility. These may prove more significant barriers than technical design.
- **Fifth**, The focus on delhi limits generalizability to other states with different governance structures and procurement systems.

VI. CONCLUSION

This paper has proposed a unified approach to biomedical inventory management for delhi government hospitals, addressing documented deficiencies in classification, visibility, and lifecycle management. Drawing on validated inventory control theory, delhi-specific evidence of systemic failure, and comparative data demonstrating achievable performance benchmarks, the framework integrates abc-ved classification, lifecycle-aware asset tracking, and standardized data architecture.

The mathematical models—criticality-weighted eoq, multi-objective procurement optimization, surplus redeployment scoring, and stockout risk quantification—provide

operational tools for implementing the framework. Projected improvements include 12–14 percentage point gains in equipment uptime, 90% reduction in vital item stockouts, and 62% redeployment of surplus assets within 90 days.

The core insight is that delhi's inventory management problems are primarily procedural and organizational, not resource-driven. The ilbs comparison demonstrates that high performance is achievable within the same system.

Standardization—of classification criteria, data formats, and governance structures—is the essential intervention. Implementation requires sustained political commitment, technical capacity building, and phased rollout with rigorous evaluation. The gtb ventilator surplus and chronic medicine stockouts represent unacceptable costs of the current fragmented approach; the unified framework offers a viable path toward their elimination.

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